Overall Heat Transfer Coefficients of Copper-Nickel Condenser Tubes

By

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by

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CERTIFICATE OF APPROVAL

This thesis is accepted and approved in partial fulfillment of the requirements for the degree of Master of Science.

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This project was proposed by the Heat Transfer Section, Ship Technical Branch, Bureau of Ships, Navy Department for student officers of the United States Naval Postgraduate School, Annapolis, Maryland. It was carried out at Lehigh University under the supervision of Dr. Darrel E. Mack, to whom the authors express their appreciation for his helpful criticism and suggestions.

Recognition is due also to The Heat Exchange Institute which sponsored the original installation of this equipment and previous investigations in the field of heat transfer in condenser tubes by the Lehigh University Institute of Research.

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SUMMARY

This paper presents overall heat transfer coefficients of 70-30 copper-nickel condenser tubes. Tests were run on small size tubes with steam at 100°F condensing on the outside surface. Water was circulated through the tubes at high velocities and at a wide range of temperatures.

Charts showing the variation of overall heat transfer coefficients with change in water velocity for the three tube sizes at different water temperatures are presented. Correction factors are presented which, when applied to the overall heat transfer coefficient as calculated by the general equations, may be used to predict the overall heat transfer coefficient within a probable deviation of two percent from the actual experimental value.

Details are given of the apparatus and of experimental procedure.

STATEMENT OF THE PROJECT

The Heat Transfer Section, Ship Technical Branch, Bureau of Ships, in a memorandum dated 14 April 1947, suggested the following thesis subject for student officers of the naval engineering group at the U. S. Naval Postgraduate School:

"Study of Heat Transfer rates in condenser tubes at velocities between 7 feet per second and 15 feet per second. The study should cover 70:30 copper-nickel tubes, 5/8" and/or 1/2" O. D., #18 BWG and/or #20 BWG wall thickness."

In this study the steam temperature was held constant at 100°F for all runs. The circulating water velocity was extended above the proposed maximum to 21 feet per second. Inlet water temperature was varied between 80° and 45°F. Copper-nickel tubes of the following sizes were tested:

5/8 inch O. D., 18 BWG

1/2 inch O. D., 18 BWG

1/2 inch O. D., 20 BWG

GENERAL DESCRIPTION OF THE EQUIPMENT

The equipment is most easily described by considering the two separate recycling systems — steam and circulating water.

Steam System

Steam generated under vacuum in the evaporator passes through the calorimeter around the condenser tube. The steam condensate which forms and drips from the tube is collected and returned to the evaporator. That portion of the steam not condensed on the tube goes to a surface condenser from which the condensate is also returned to the evaporator. The vacuum pump removes any non-condensables from the vapors in the condenser and maintains the system at a pressure considerably below atmospheric (about 28 inches of mercury vacuum). Accurate control of the vacuum, and consequently, of steam temperature, is obtained by regulating the rate of cooling water flow through the condenser.

Circulating Water System

Circulating water flows from the constant head tank through the condenser tube in the calorimeter to the multiple-orifice tank flowmeter. A cock adjacent to this flowmeter serves for adjusting the flow rate and holding it constant during a run.

Circulating water leaving the multiple-orifice tank flowmeter falls into a weigh tank, used for calibration, and then passes through the circulating water cooler to the supply tank. Regulating the rate of cooling water flow to this cooler controls the temperature of the circulating water at the inlet to the condenser tube in the calorimeter.

The circulating pump takes suction from the supply tank and returns the water to the constant head tank. The overflow from the constant head tank may be cooled in the overflow cooler before returning to the supply tank. In order to obtain higher velocities through the condenser tube the constant head tank is by-passed, and circulating water enters the tube directly at pump pressure.

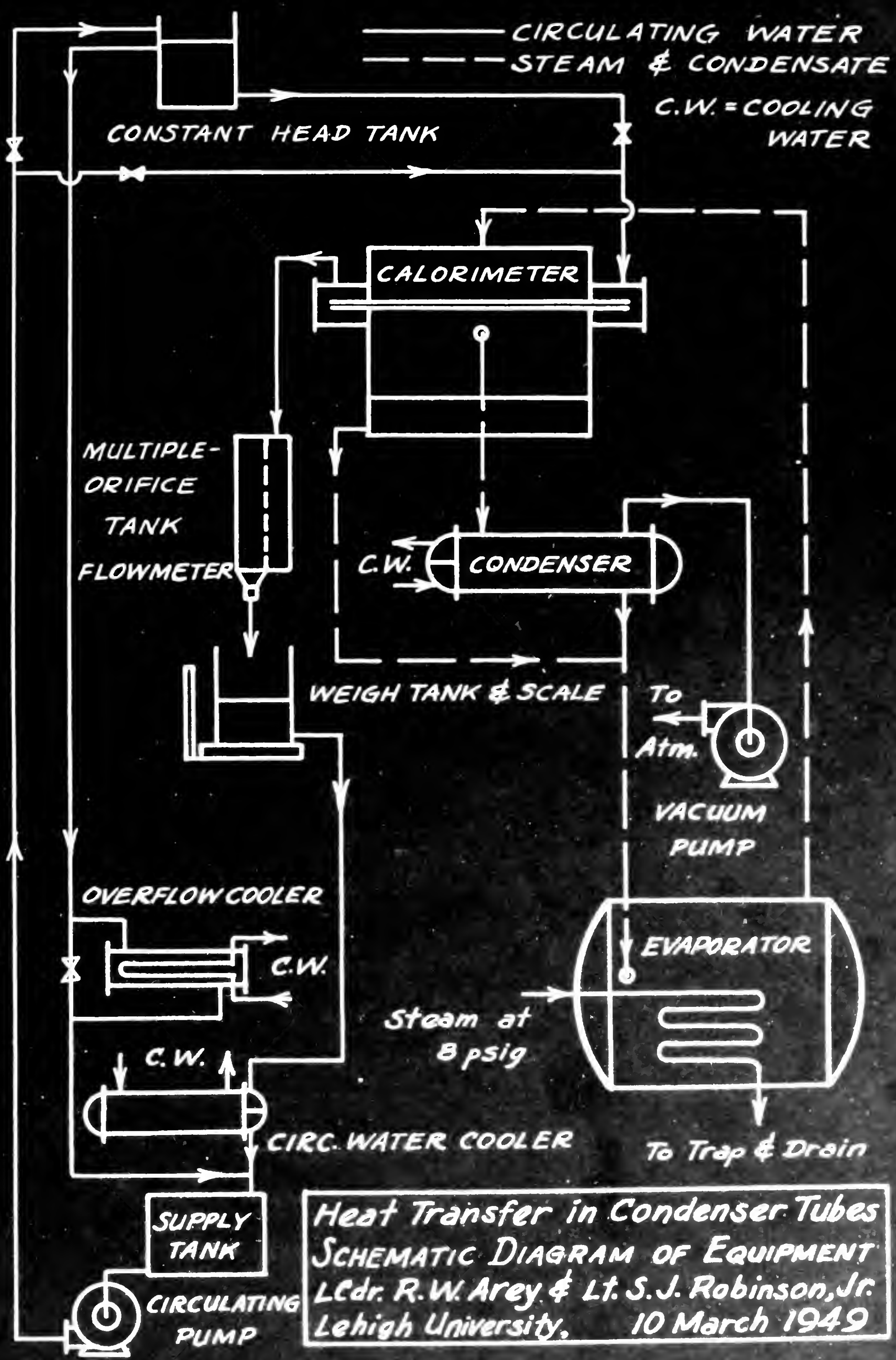

CIRCULATING WATER
STEAM & CONDENSATE
C.W. = COOLING WATER
CONSTANT HEAD TANK
CALORIMETER
MULTIPLE-ORIFICE TANK FLOWMETER
C.W.
CONDENSER
WEIGH TANK & SCALE
To Atm.
VACUUM PUMP
OVERFLOW COOLER
C.W.
EVAPORATOR
Steam at 8 psig
C.W.
CIRC. WATER COOLER
To Trap & Drain
SUPPLY TANK
CIRCULATING PUMP
Heat Transfer in Condenser Tubes
SCHEMATIC DIAGRAM OF EQUIPMENT
LCdr. R.W. Arey & Lt. S.J. Robinson, Jr.
Lehigh University, 10 March 1949

FIG. 1

DETAILS OF THE EQUIPMENT

Calorimeter

The calorimeter is a steel chamber (14"x36"x64") with internal baffles so arranged that the entire volume of steam passing through the system flows across the condenser tube under test.

A single condenser tube about two feet longer than the calorimeter is inserted horizontally. The extra length of tube extends into the two end fittings where a baffle arrangement causes the water entering and leaving to pass over the exterior surface of the tube ends. This prevents any radiation effects upon the tube ends and limits the heat transfer surface of the tube to the interior length of the calorimeter.

Multiple-Orifice Tank Flowmeter

The flowmeter is a sheet aluminum tank (8"x12"x42") and sight glass, with a series of 3/8 inch diameter orifices in the vertical dividing wall. The maximum capacity of the flowmeter is 25 gallons per minute.

Actual calibration data, obtained using the weigh tank and scale for timed runs and plotted as gauge reading (H cm.) against circulating water flow rate (w lb./hr.), produced a family of intersecting curves, particularly for the high flow rates; the points of intersection coincided with the positions of the orifices.

Evaporator

The evaporator is of the submerged coil type operated from the laboratory main steam line. The water level remains constant during a series of runs (one-half full) since all condensate is returned to the evaporator.

A reducing and regulating valve assembly supplies steam for heating

the coil at eight pounds per square inch reduced from 120-160 pounds per square inch. This establishes approximately constant steam velocities across the condenser tube for all runs.

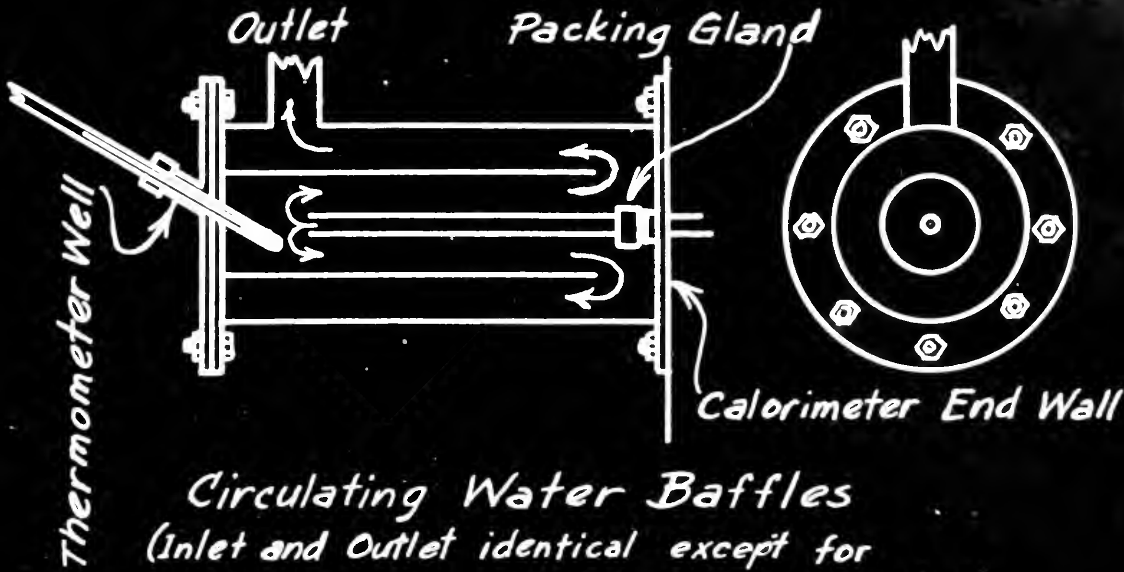
(See APPENDIX)

Vacuum Pump

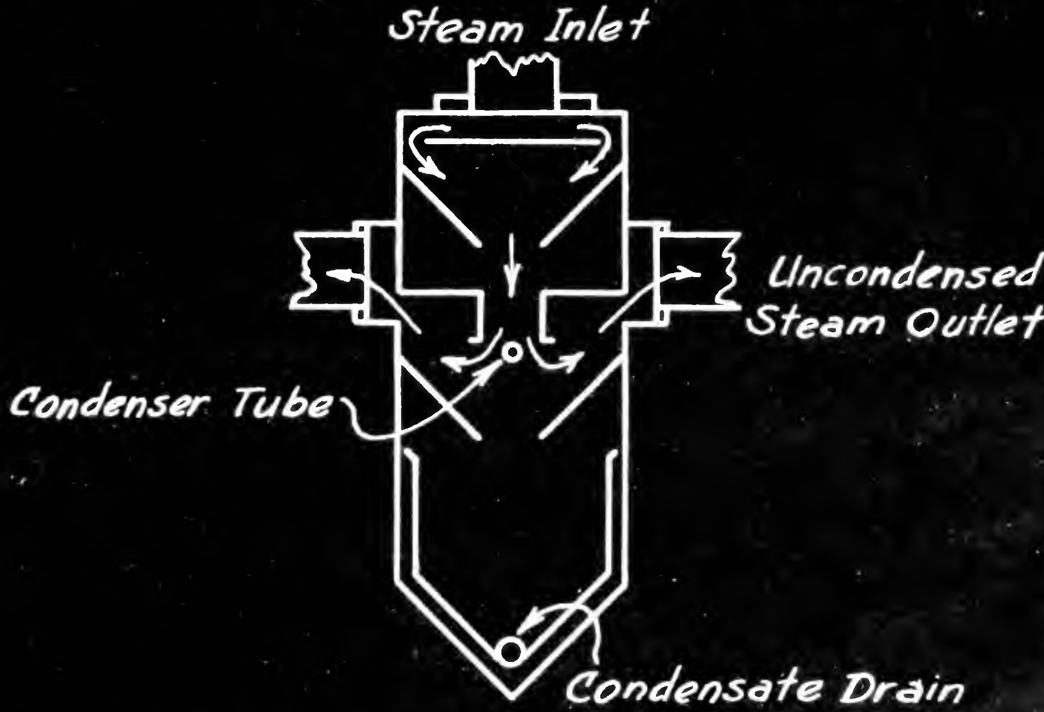
Two Nash "Hytor" vacuum pumps, size TS-7, Test Nos. H-1641 and H-1642, in series.

Circulating Pump

Ingersoll-Rand "Motorpump", Model B, Serial No. 0241714, 20 gallons per minute at a head of 50 feet.



Circulating Water Baffles
(Inlet and Outlet identical except for opposite flow of circulating water.)



Calorimeter Steam Baffles

Heat Transfer in Condenser Tubes
Details of Calorimeter
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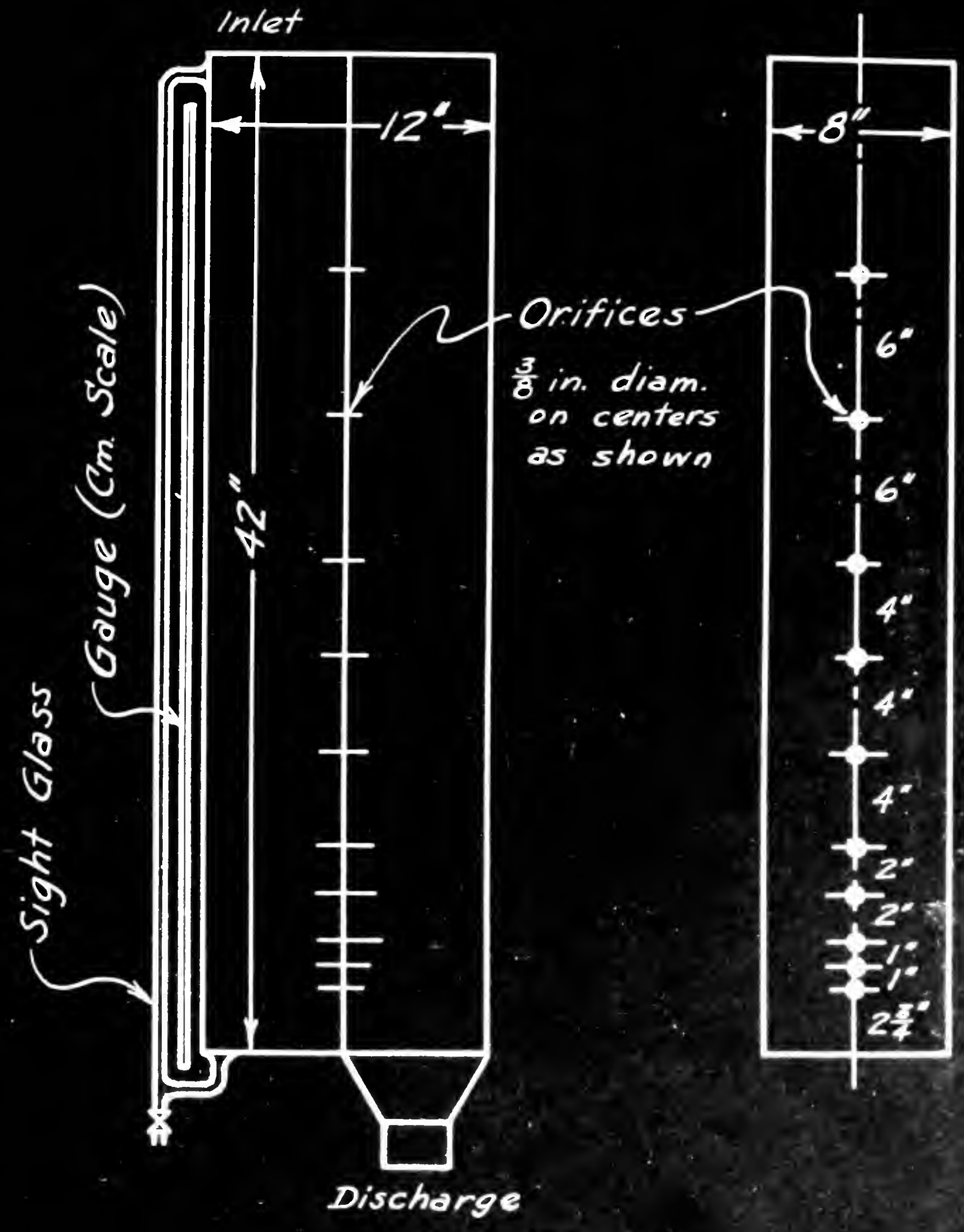
Lehigh University 29 March 1949

FIG. 2



Heat Transfer in Condenser Tubes
MULTIPLE-ORIFICE TANK FLOWMETER
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Lehigh University, 10 March 1949

FIG. 3

METHOD OF OPERATION

In preparation for data runs on the equipment, water was first circulated through the system and adjusted approximately to the required inlet temperature by means of the circulating water cooler and the overflow cooler if too warm, and by a steam line to the supply tank if too cool. The vacuum pump was started to reduce the pressure in the steam system to about 28 inches of mercury vacuum.

Next the steam supply to the evaporator was opened, and cooling water passed through the condenser. The steam temperature in the calorimeter was adjusted by regulating the amount of cooling water through the condenser. A cock located above the multiple-orifice tank flowmeter was then set for the required rate of flow through the condenser tube.

After making fine adjustments to the steam and water temperatures and flow rate, the system was allowed to reach equilibrium and a series of readings was taken at intervals of five minutes for a period of not less than 15 minutes. The following data was recorded:

Steam temperature, t_s $^{\circ}F$

Inlet water temperature, t_1 $^{\circ}F$

Outlet water temperature, t_2 $^{\circ}F$

Flowmeter gauge reading, H cm.

Steam pressure, in. Hg (vacuum)

Atmospheric pressure, in. Hg

For all runs the steam temperature was held constant at $100^{\circ}F$, within plus or minus one degree. The inlet water temperature was maintained variously at 80°, 70° and $60^{\circ}F$, within plus or minus one degree. A few

series of runs were made at 55° and $45^{\circ}F$, but as these were dependent upon weather conditions (temperature of water from underground lines), such close temperature control was not possible. Water from the City of Bethlehem supply main was used in both steam and circulating water system.

SAMPLE CALCULATIONS

The equation, $q = UA\Delta t_m$, was used to calculate U, the overall heat transfer coefficient based on the outside tube area. The heat transfer rate q, was calculated from the temperature rise and flow rate of circulating water through the condenser tube, A was measured, and Δt_m was the log mean temperature difference between the steam and the water.

The data taken for a single typical run is shown below:

Run Number 56

Time	t_3	t_1	t_2	H
0	100.58	79.80	85.85	20.6
5	99.38	79.75	85.50	20.6
10	99.30	79.80	85.55	20.6
15	99.00	79.80	85.50	20.6
20	99.77	79.85	85.70	20.6
Average	99.36	79.80	85.56	20.6
Correction	-0.08	-0.09	+0.06	
Corrected Average	99.28	79.71	85.62	20.6

Only the last four readings were averaged as the equipment apparently had not reached equilibrium when the zero reading was taken.

The three therometers used were calibrated against a Bureau of Standards therometer, and curves were drawn for use in correcting the average reading to true ^{o}F.

<u>Water Flow Rate (w)</u>

The flowmeter gauge was calibrated by weighing the amount of water which passed through it per unit of time. A graph was constructed using gauge reading as the abscissa vs. pounds per hour as the ordinate.

$$H = 20.6 \text{ cm.} \qquad w = 1820 \text{ lb./hr.}$$

And from the tube dimension the 1820 pounds per hour was easily converted to $V = 8.0$ feet per second.

Total Heat Transfer Rate (q)

The total heat transferred from the tube to the circulating water was calculated from the value of w found above, the difference between the heated water and inlet water temperature, and the specific heat of the water, which is 0.997 BTU per pound - $^{\circ}F$ in this example, by means of the equation:

$$q = w\,(t_2 - t_1)c$$

$$q = 1820(85.62-79.71)\ 0.997 = 10{,}720 \text{ BTU/hr.}$$

Outside Tube Area (A)

Run number 56 was made on a $\frac{1}{2}$ inch, 20 BWG tube, 61.56 inches effective tube length. From tables of condenser tube dimensions it was found that the outside area is 0.1309 square feet per foot of tube. Hence, the total outside area is:

$$A = 0.1309 \times 61.56/12 = 0.671 \text{ sq. ft.}$$

Log Mean Temperature Difference (Δt_m)

The log mean temperature difference was used:

$$\Delta t_m = \frac{(t_s-t_1)-(t_s-t_2)}{\ln \dfrac{t_s - t_1}{t_s - t_2}} = \frac{5.91}{\ln \dfrac{19.57}{13.66}} = 16.48^{\circ}F$$

Overall Heat Transfer Coefficient (U)

The overall heat transfer coefficient, U, was calculated as follows:

$$U = \frac{q}{A\,\Delta t_m} = \frac{10{,}720}{0.671 \times 16.48}$$

$$U = 971 \quad \text{BTU / hr. - sq. ft. - } ^{\circ}F$$

TABLES OF DATA

Table I.
Tube Size: 5/8 in. O. D., 18 BWG   Water Inlet Temperature: 80°F

Run	t_s	t_1	t_2	H	w	q	Δt_m	V	U
76*	99.7	79.75	84.83	23.6	2330	11800	17.27	6.8	817
1	99.30	80.18	85.01	23.8	2380	11460	16.59	7.0	824
10	100.85	79.91	85.24	23.8	2380	12640	18.22	7.0	827
2	99.18	80.49	84.91	25.4	2720	12000	16.38	8.0	874
3	99.20	80.48	84.64	27.3	3060	12680	16.50	9.0	915
11	100.58	79.91	84.49	27.4	3070	14010	18.05	9.05	925
77*	100.1	80.01	84.16	29.6	3410	14100	17.97	10.0	937
4	100.28	80.64	84.79	29.7	3440	14220	17.43	10.1	973
5	100.48	80.97	84.87	32.2	3740	14540	17.48	11.0	993
12	100.41	79.89	83.92	33.0	3820	15360	18.39	11.2	996
6	100.01	80.46	84.15	34.2	4075	14990	17.70	12.0	1010
78*	99.7	79.70	83.22	35.9	4390	15410	18.23	12.9	1007
7	100.66	80.47	84.00	36.0	4415	15540	18.30	13.0	1013
13	100.53	80.09	83.67	36.0	4415	15750	18.55	13.0	1013
8	100.05	80.37	83.65	38.2	4755	15540	18.00	14.0	1030
9	99.91	80.25	83.39	41.2	5095	15940	18.15	15.0	1048
14	100.29	80.04	83.25	41.2	5095	16300	18.62	15.0	1042
16	99.14	79.46	82.61	41.4	5120	16100	18.10	15.1	1060
17	99.23	79.61	82.62	43.9	5420	16250	18.00	16.0	1076
22	100.16	79.81	82.90	44.0	5440	16750	18.69	16.0	1069
79*	99.9	79.59	82.61	44.0	5440	16380	18.85	16.0	1035
23	100.34	80.20	83.09	45.9	5800	16700	18.62	17.1	1069
15	100.05	79.42	82.34	46.7	5940	17290	19.11	17.5	1078
18	99.89	79.64	82.54	46.7	5940	17160	18.68	17.5	1093
25	99.48	79.73	82.44	47.8	6120	16530	18.36	18.0	1073
80*	99.8	80.00	82.62	49.9	6420	16770	18.53	18.9	1079
26	100.23	79.73	82.46	50.3	6470	17600	19.18	19.0	1096
24	100.19	79.92	82.51	53.2	6770	17480	18.88	19.9	1103
27	100.16	79.51	82.07	53.7	6810	17380	19.27	20.0	1075

(* indicates Tube No. 2)

Data from report for The Heat Exchange Institute, Lehigh U. Inst. of Research, 5 Sept. 1947:

t_s	t_1	t_2	V	U
100.15#	80.0#	85.60	6	785
		85.10	7	820
		84.80	8	876
		84.50	9	916
		84.20	10	944
		84.00	11	984
		83.75	12	1023
		83.6	13	1033
		83.55	14	1096

(# indicates average for all runs)

Run	t_s	t_1	t_2	H	w	q	Δt_m	V	U
Table II.									
Tube Size: 5/8 in. O. D., 18 BWG						Water Inlet Temperature: 70°F			
81	99.3	69.86	77.09	23.8	2380	17180	25.70	7.0	798
106	99.1	69.16	76.26	24.0	2420	17150	26.30	7.1	778
90	100.2	69.70	76.52	25.4	2720	18500	27.05	8.0	816
82	99.5	69.56	75.96	27.4	3080	19670	26.70	9.1	878
107	99.8	69.06	75.11	29.4	3390	20450	27.60	10.0	862
83	99.4	69.82	75.54	32.3	3750	21400	26.80	11.0	952
89	100.6	70.49	76.04	34.1	4060	22500	27.20	11.9	987
84	99.4	70.18	75.30	36.0	4415	22530	26.50	13.0	1013
85	100.3	70.35	75.09	41.3	5100	24100	27.50	15.0	1043
108	100.0	69.65	74.18	43.9	5420	24500	27.90	15.9	1045
86	99.5	69.16	73.41	45.9	5800	24600	28.13	17.1	1041
88	100.4	69.72	73.95	47.6	6080	25670	28.50	17.9	1072
109	99.8	69.03	73.06	50.3	6470	26000	28.80	19.0	1076
87	99.8	69.48	73.32	53.4	6790	26700	28.70	20.0	1110
Table III.									
Tube Size: 5/8 in. O. D., 18 BWG						Water Inlet Temperature: 60°F			
200	100.8	60.56	70.13	23.8	2380	22650	35.35	7.0	765
206	99.7	59.84	68.57	25.4	2710	23600	35.35	8.0	797
205	99.5	59.38	67.61	27.3	3060	25150	35.85	9.0	837
201	100.1	60.49	68.31	29.5	3400	26550	35.7	10.0	854
204	100.0	61.34	68.44	32.2	3740	26500	34.85	11.0	906
202	99.5	60.85	67.79	34.2	4080	28250	35.0	12.0	962
203	100.3	60.48	66.80	38.2	4750	30000	36.5	14.0	981
207	99.6	60.01	65.76	43.8	5400	31000	34.7	15.9	1065
Table IV.									
Tube Size: 5/8 in. O. D., 18 BWG						Water Inlet Temperature: 53-58°F			
91	100.0	57.22	66.92	23.8	2380	23050	37.6	7.0	731
101	100.9	55.58	65.79	23.9	2400	24470	40.0	7.1	730
100	100.8	54.92	64.76	25.4	2710	26650	40.8	8.0	779
92	100.1	56.20	64.98	27.4	3070	26900	39.2	9.0	818
102	100.2	54.72	63.31	29.5	3400	29200	41.2	10.0	845
93	99.9	55.09	63.21	32.2	3740	30350	40.7	11.0	890
99	100.4	54.57	62.57	34.9	4220	33750	41.9	12.4	962
94	99.6	54.40	61.94	36.1	4430	33400	41.3	13.0	965
103	100.1	54.56	61.56	38.7	4810	33700	42.1	14.1	955
95	99.7	53.75	60.65	41.1	5080	35050	42.3	15.0	987
104	101.2	53.43	60.25	44.3	5500	37500	44.2	16.2	1010
96	99.7	53.85	60.15	45.7	5760	36300	42.7	17.0	1013
98	100.4	53.86	60.00	47.6	6080	37300	43.4	17.9	1023
105	100.2	53.60	59.25	52.7	6720	38000	43.4	19.8	1042
97	100.5	53.91	59.51	53.3	6780	37950	43.6	19.9	1037

Table V.
Tube Size: 1/2 in. O. D., 18 BWG — Water Inlet Temperature: 80 °F

Run	t_s	t_1	t_2	R	w	q	Δt_m	V	U
28	99.57	80.02	86.38	17.8	1380	8750	16.17	7.0	806
49	100.17	79.75	86.42	17.9	1400	9300	16.84	7.1	823
46	100.77	80.12	86.54	19.1	1580	9960	1697	8.0	875
29	100.10	79.97	86.23	19.2	1600	10000	16.84	8.1	886
30	100.06	80.33	85.84	20.3	1780	9780	16.79	9.0	868
50	99.83	79.91	85.59	20.3	1780	10080	16.87	9.0	890
31	100.33	80.10	85.38	21.6	1980	10410	17.47	10.0	888
47	100.18	79.96	85.32	21.6	1980	10580	17.39	10.0	907
32	100.20	79.67	84.88	22.9	2190	11370	17.80	11.1	952
33	100.20	79.65	84.69	23.7	2360	11870	17.90	11.9	988
45	100.45	80.24	85.05	24.7	2570	12300	17.75	13.0	1032
34	100.61	80.14	84.93	24.9	2610	12450	17.90	13.2	1036
35	100.75	80.42	84.90	25.7	2770	12370	17.98	14.0	1025
51	99.55	79.96	84.33	25.7	2770	12080	17.32	14.0	1038
36	100.62	80.45	84.78	26.4	2890	12490	18.04	14.6	1032
48	100.61	80.04	84.33	26.8	2960	12690	18.37	15.0	1029
52	99.60	79.88	84.07	26.8	2960	12370	17.52	15.0	1051
37	99.33	79.89	84.07	26.9	2980	12400	17.20	15.1	1074
38	99.97	79.78	83.94	28.0	3170	13150	18.07	16.1	1085
39	100.43	79.94	84.01	29.2	3360	13640	18.39	17.0	1107
40	99.97	79.99	83.76	30.7	3560	13390	18.08	18.0	1103
44	100.56	79.99	83.92	30.7	3560	13930	18.58	18.0	1118
41	100.19	79.28	83.08	32.3	3750	14200	19.03	19.0	1111
53	99.63	79.88	83.50	32.4	3760	13580	18.05	19.0	1120
42	100.18	79.29	83.01	33.6	3950	14660	18.78	20.0	1161
43	100.20	79.80	83.33	34.6	4150	14570	18.59	21.0	1168
54	100.16	79.80	83.33	34.6	4150	14600	18.59	21.0	1170

Table VI.
Tube Size: 1/2 in. O. D., 18 BWG — Water Inlet Temperature: 70 °F

Run	t_s	t_1	t_2	R	w	q	Δt_m	V	U
123	100.6	69.26	79.21	17.6	1340	13320	26.07	6.8	762
125	100.9	69.67	79.58	17.8	1380	13650	25.95	7.0	784
118	100.9	69.58	79.00	19.0	1570	14760	26.4	8.0	833
120	100.0	70.04	79.12	19.2	1600	14500	25.2	8.1	857
126	99.6	69.66	78.14	20.2	1770	14990	25.5	9.0	877
124	100.1	69.29	77.78	20.4	1790	15160	26.3	9.1	860
121	99.5	69.19	77.01	21.6	1980	15450	26.25	10.0	877
112	100.1	70.40	77.46	22.8	2170	15300	26.0	11.0	879
127	99.5	70.12	77.50	22.8	2170	15960	25.4	11.0	936
122	100.1	69.20	76.60	23.8	2380	17590	27.0	12.0	970
128	99.7	69.61	76.51	24.6	2550	17530	26.5	12.9	987
113	99.7	70.23	76.70	24.7	2570	16600	26.1	13.0	950
114	100.4	71.33	77.10	26.8	2970	17100	26.1	15.0	979
129	100.8	70.17	76.46	26.8	2970	18630	27.3	15.0	1018
119	100.7	69.75	76.11	26.9	2980	18910	27.6	15.1	984
115	100.0	69.64	75.40	29.3	3370	19370	27.4	17.1	1053
130	100.0	70.08	75.81	29.3	3370	19270	26.9	17.1	1067
133	100.2	70.01	75.66	30.7	3560	20070	27.3	18.0	1095
116	100.1	70.73	75.94	32.3	3750	19500	26.5	19.0	1096
132	100.8	70.24	75.63	33.6	3950	21200	27.8	20.0	1137
117	100.4	70.64	75.66	34.6	4150	20800	27.3	21.0	1135
131	100.4	69.73	75.00	34.6	4150	21800	28.0	21.0	1160

Run	t_s	t_1	t_2	R	w	q	Δt_m	V	U

Table VII.
Tube Size: 1/2 in. O. D., 18 BWG — Water Inlet Temperature: 60°F

Run	t_s	t_1	t_2	R	w	q	Δt_m	V	U
191	100.8	59.93	72.21	17.9	1400	17170	34.3	7.1	745
194	99.8	60.51	71.62	19.1	1580	17540	33.45	8.0	782
192	100.0	59.56	69.54	21.7	2000	19960	35.3	10.1	843
195	99.3	60.28	69.49	22.8	2170	19950	34.1	11.0	872
193	100.0	59.93	68.78	24.8	2590	22900	35.5	13.1	962
196	99.5	60.57	68.68	25.7	2770	22450	34.85	14.0	960
199	100.0	60.33	68.40	26.6	2930	23600	35.4	14.8	995
198*	99.9	59.50	66.36	32.3	3750	35700	37.1	19.0	1031
142	100.0	59.15	66.08	33.6	3950	27330	37.15	20.0	1097
197*	99.7	59.84	66.66	34.3	4100	37900	36.2	20.7	1149

(* indicates questionable data; calculated from only one reading)

Table VIII.
Tube Size: 1/2 in. O. D., 18 BWG — Water Inlet Temperature: 52-58°F

Run	t_s	t_1	t_2	R	w	q	Δt_m	V	U
134	100.3	53.91	66.28	17.8	1380	17040	39.75	7.0	639
140	100.2	56.93	69.16	17.8	1380	16870	36.8	7.0	684
137	100.1	54.38	66.51	19.1	1580	19180	39.5	8.0	724
139	100.2	54.72	66.49	20.3	1780	20900	39.2	9.0	795
136	100.4	56.56	66.97	21.6	1980	20600	38.5	10.0	797
141	100.2	57.35	67.04	22.8	2170	21000	37.8	11.0	828
138	100.1	52.24	62.58	23.9	2400	24800	42.5	12.1	870
135	99.8	54.71	64.91	24.7	2570	26200	39.8	13.0	980

Table IX.
Tube Size: 1/2 in. O. D., 18 BWG — Water Inlet Temperature: 42-50°F

Run	t_s	t_1	t_2	R	w	q	Δt_m	V	U
143	100.5	47.53	61.25	17.8	1380	18950	45.8	7.0	617
151	100.8	50.03	61.73	17.8	1380	16150	44.75	7.0	538
146	100.1	47.87	60.79	19.0	1570	20330	45.45	8.0	667
160	100.4	49.26	60.83	19.0	1570	18190	45.2	8.0	600
149	100.6	49.72	60.12	20.3	1780	18550	45.5	9.0	608
144	100.4	48.52	58.35	21.5	1970	19390	46.9	10.0	616
147	100.2	46.97	57.90	22.8	2170	23750	47.7	11.0	743
150	100.6	49.43	57.81	23.9	2400	20130	46.85	12.0	641
159	100.4	47.33	56.95	23.8	2380	22950	48.0	12.0	713
145	100.6	47.23	56.47	24.7	2570	23800	48.7	13.0	729
148	99.7	46.46	56.11	25.7	2770	26750	48.55	14.0	822
152	100.1	44.52	54.32	26.7	2950	29000	50.4	14.9	858
158	100.8	43.34	53.35	27.9	3160	31700	52.3	16.0	904
153	99.5	44.33	53.08	29.0	3340	29300	50.55	16.9	865
157	100.0	43.68	52.90	30.7	3560	32900	51.8	18.0	947
154	99.9	43.18	51.98	32.1	3730	32900	52.1	18.9	940
156	100.8	42.50	51.23	33.6	3950	34500	54.1	20.0	951
155	100.6	43.84	52.32	34.4	4120	35000	52.3	20.9	998

Table X.
Tube Size: 1/2 in. O. D., 20 BWG — Water Inlet Temperature: 80 °F

Run	t_s	t_1	t_2	H	w	q	Δt_m	V	U
55	99.53	79.77	86.37	19.0	1570	10330	16.21	6.9	950
70	99.8	79.72	86.49	19.2	1600	10800	16.47	7.1	978
56	99.28	79.71	85.62	20.6	1820	10720	16.48	8.0	971
57	100.38	79.91	85.74	22.1	2060	11970	17.36	9.1	1028
75	100.4	80.13	85.59	23.2	2240	12860	17.24	9.9	1111
58	100.52	80.28	85.82	23.3	2260	12470	17.27	10.0	1077
59	100.02	79.85	85.13	24.5	2530	13310	17.46	11.2	1138
60	100.33	80.06	84.96	25.8	2780	13590	17.65	12.3	1147
61	100.50	80.11	84.92	26.6	2940	14090	17.81	13.0	1179
62	99.97	80.11	84.54	28.0	3170	13990	17.60	14.0	1183
71	99.9	80.30	84.90	28.0	3170	14530	17.23	14.0	1257
63	99.85	80.15	84.40	29.5	3400	14390	17.50	15.0	1226
64	99.85	80.08	84.38	31.0	3600	15430	17.52	15.9	1313
72	99.8	80.03	84.34	31.2	3620	15520	17.93	16.0	1290
65	100.14	79.97	84.15	33.2	3870	16130	18.02	17.1	1334
66	100.17	79.93	84.02	34.3	4100	16720	18.15	18.1	1372
73	99.6	80.16	84.11	34.3	4100	16140	17.40	18.1	1382
67	100.0	79.85	83.70	35.4	4300	16500	18.11	19.0	1358
68	100.1	79.86	83.57	36.8	4540	16800	18.28	20.0	1370
69	99.3	79.81	83.23	38.1	4730	16110	17.71	20.9	1355
74	99.9	80.15	83.68	38.1	4730	16640	17.99	20.9	1378

Table XI.
Tube Size: 1/2 in. O. D., 20 BWG — Water Inlet Temperature: 70 °F

Run	t_s	t_1	t_2	H	w	q	Δt_m	V	U
161	101.0	69.90	79.47	19.1	1580	15100	25.93	7.0	867
164	99.5	70.11	78.49	20.5	1810	15130	25.0	8.0	903
171	99.7	70.04	77.82	22.0	2040	15820	25.6	9.0	922
162	100.8	69.74	77.64	23.3	2260	17800	26.95	10.0	985
165	100.3	69.79	77.45	24.2	2470	18890	26.6	10.9	1059
172	99.9	69.75	76.79	25.3	2690	18900	26.5	11.9	1062
163	100.8	69.78	76.63	26.8	2970	20300	27.5	13.1	1100
166	99.7	69.84	76.29	28.0	3170	20400	26.5	14.0	1148
170	99.9	70.27	76.46	29.7	3440	21260	26.5	15.2	1195
173	100.4	70.04	76.06	31.4	3650	21950	27.3	16.1	1199
174	99.9	69.79	75.51	33.0	3820	21800	27.3	16.9	1169
169	100.1	69.95	75.69	34.4	4120	23600	27.2	18.2	1291
175	100.2	69.94	75.32	35.5	4320	23200	27.5	19.1	1257
167	100.0	69.18	74.43	37.0	4570	23900	28.15	20.2	1267
1 68	100.2	69.72	75.00	37.8	4690	24750	27.7	20.7	1331

Table XII.
Tube Size: 1/2 in. O. D., 20 BWG   Water Inlet Temperature: 59-63 °F

Run	t_s	t_1	t_2	H	w	q	Δt_m	V	U
176	100.3	59.88	71.91	19.2	1600	19230	34.15	7.1	840
179	101.0	59.94	71.15	20.6	1820	20400	35.1	8.0	866
185	100.3	59.89	70.38	22.0	2040	21350	34.95	9.0	910
177	99.7	59.70	69.60	23.4	2290	22600	34.8	10.1	997
180	100.0	59.43	69.27	24.2	2470	24270	35.3	10.9	1025
186	99.4	59.83	68.77	25.6	2750	24550	35.0	12.2	1045
178	100.1	60.56	69.22	26.7	2950	25500	35.1	13.0	1082
181	100.0	60.06	68.40	28.1	3190	26600	35.6	14.1	1113
187	99.8	59.71	67.73	29.5	3400	27200	35.8	15.0	1132
188	100.2	62.52	70.03	31.0	3600	27000	33.65	15.9	1195
184	99.6	60.99	68.47	33.0	3820	28500	34.8	16.9	1220
189	100.1	61.41	68.65	34.1	4060	29350	34.95	18.0	1250
183	100.1	62.13	68.96	35.5	4320	29450	34.35	19.1	1280
190	100.4	61.27	67.91	36.6	4510	29900	35.9	19.9	1240
182	99.7	61.16	67.59	37.8	4690	30100	35.3	20.7	1270

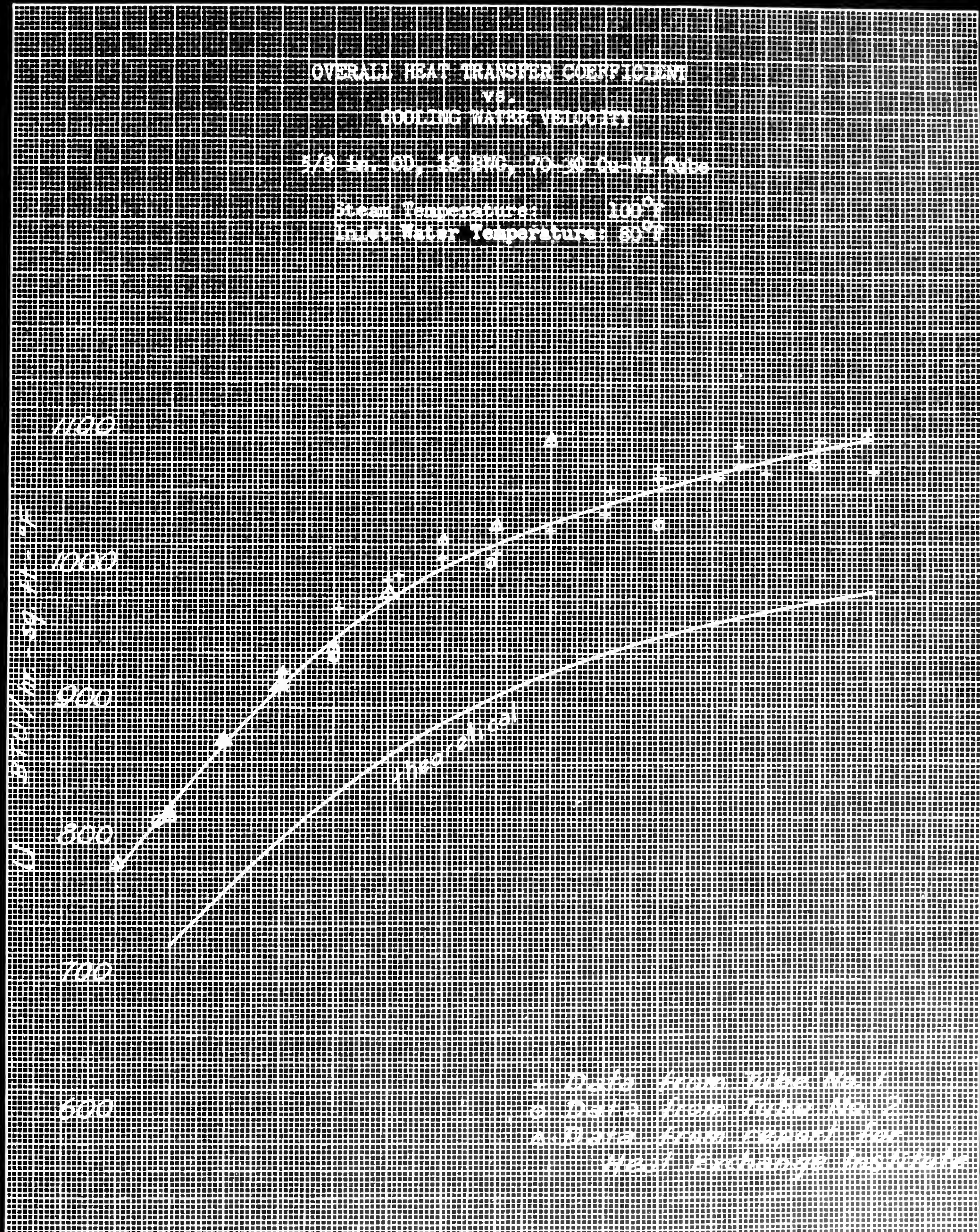
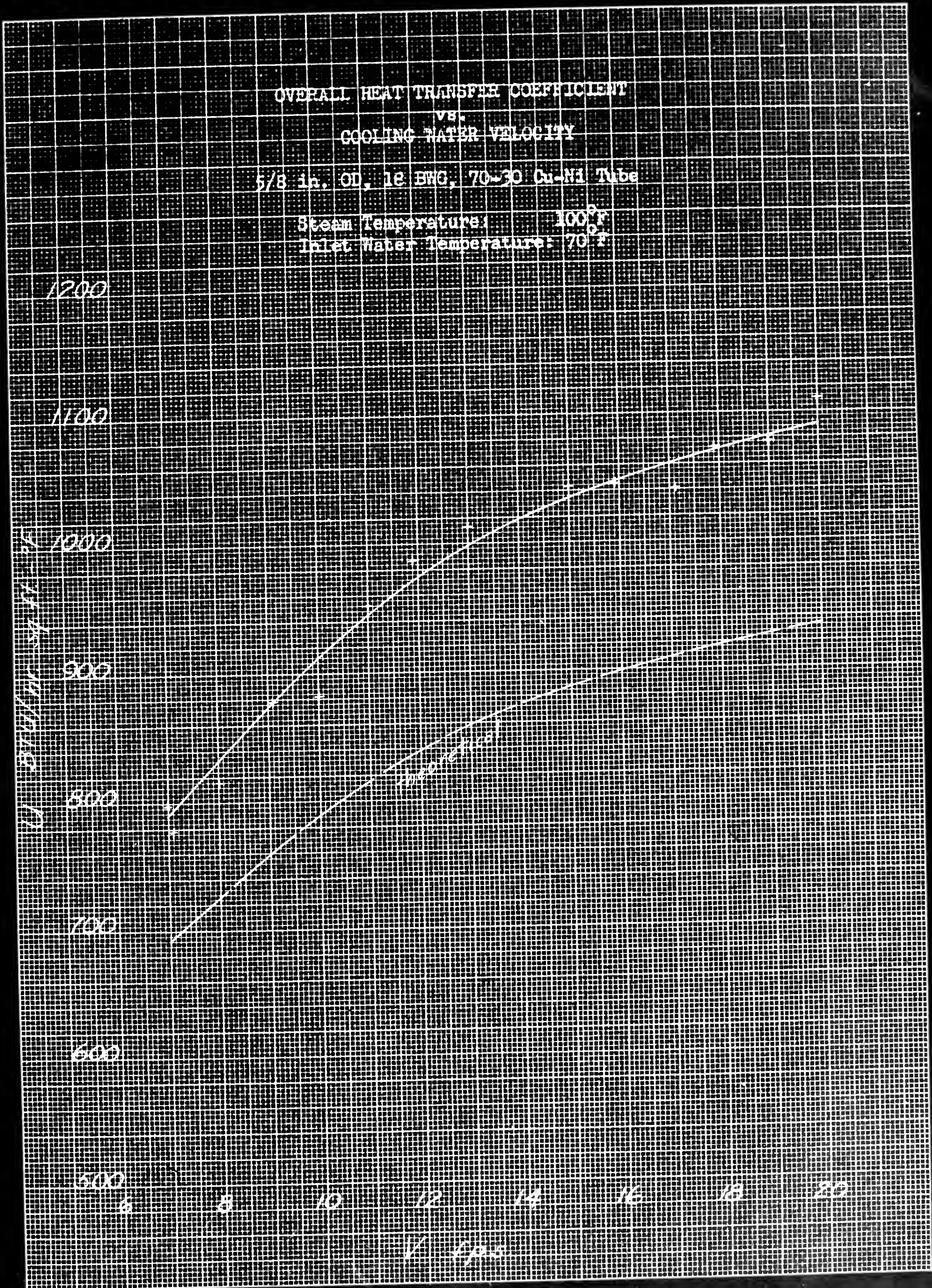

OVERALL HEAT TRANSFER COEFFICIENT
vs.
COOLING WATER VELOCITY
5/8 in. OD, 18 BWG, 70-30 Cu-Ni Tube
Steam Temperature: 100°F
Inlet Water Temperature: 80°F
1100
1000
900
800
700
600
500
6
8
10
12
14
16
18
20
U BTU/hr. sq ft. °F
Theoretical
+ Data from Tube No. 1
o Data from Tube No. 2
Δ Data from report for Heat Exchange Institute
V fps

FIG. 4



OVERALL HEAT TRANSFER COEFFICIENT
vs.
COOLING WATER VELOCITY
5/8 in. OD, 18 BWG, 70-30 Cu-Ni Tube
Steam Temperature: 100°F
Inlet Water Temperature: 70°F
1200
1100
1000
900
800
700
600
500
6
8
10
12
14
16
18
20
Theoretical
V fps

FIG. 5

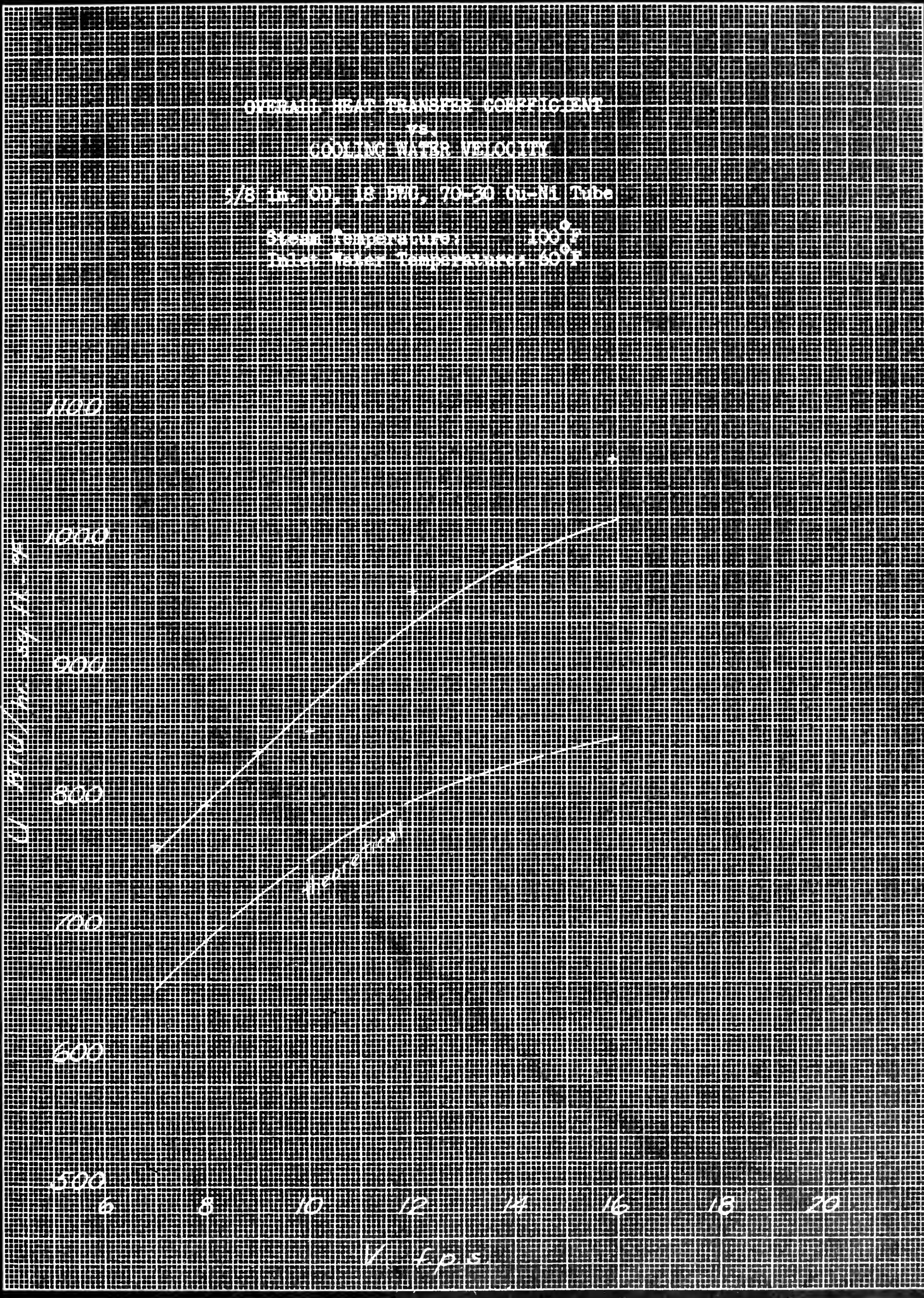

OVERALL HEAT TRANSFER COEFFICIENT
vs.
COOLING WATER VELOCITY
5/8 in. OD, 18 BWG, 70-30 Cu-Ni Tube
Steam Temperature: 100°F
Inlet Water Temperature: 60°F
1100
1000
900
800
700
600
500
6
8
10
12
14
16
18
20
V fps
theoretical

FIG. 6

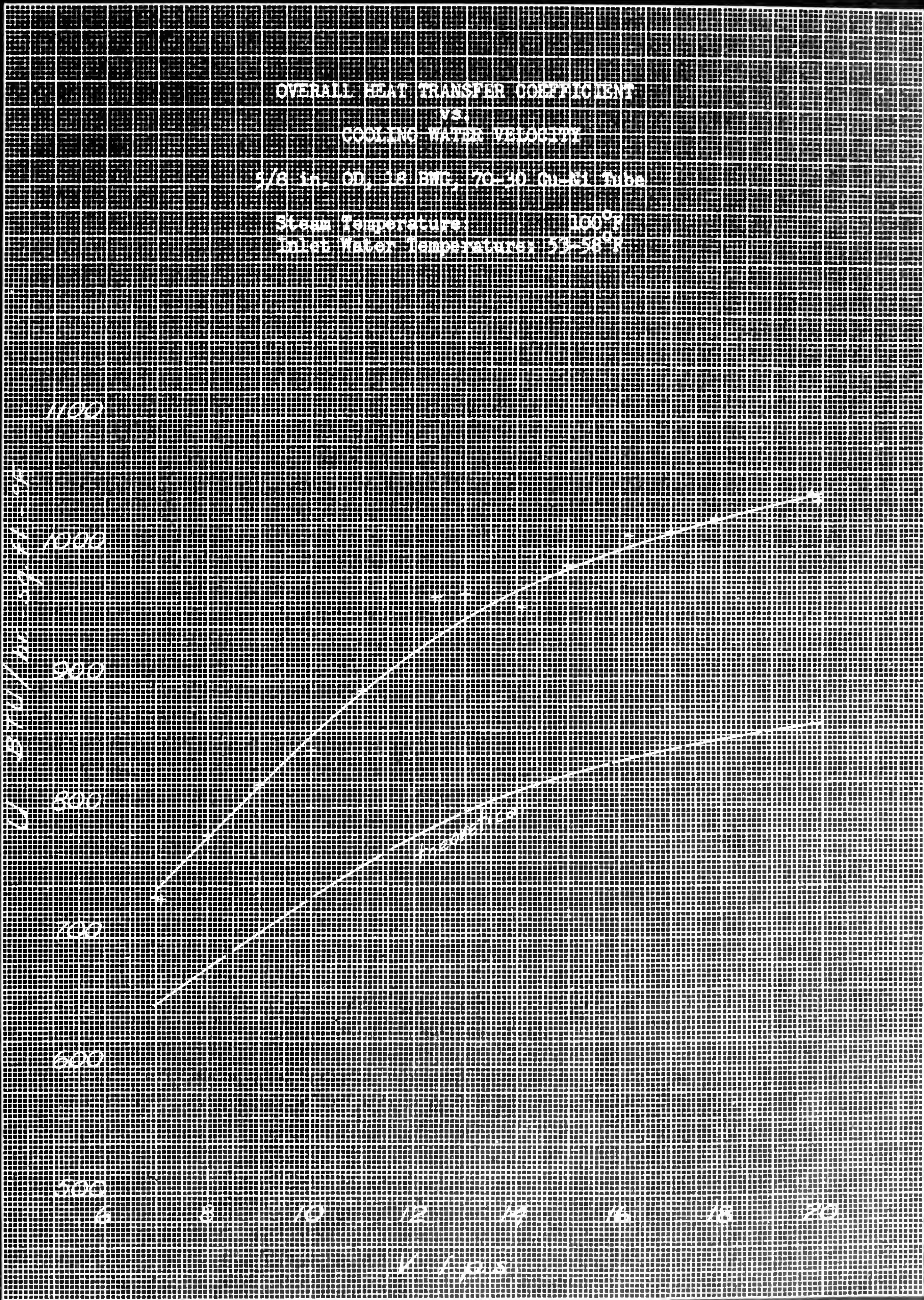

OVERALL HEAT TRANSFER COEFFICIENT
vs.
COOLING WATER VELOCITY
5/8 in. OD, 18 BWG, 70-30 Cu-Ni Tube
Steam Temperature: 100°F
Inlet Water Temperature: 53-58°F
1100
1000
900
800
700
600
500
6
8
10
12
14
16
18
20

FIG. 7

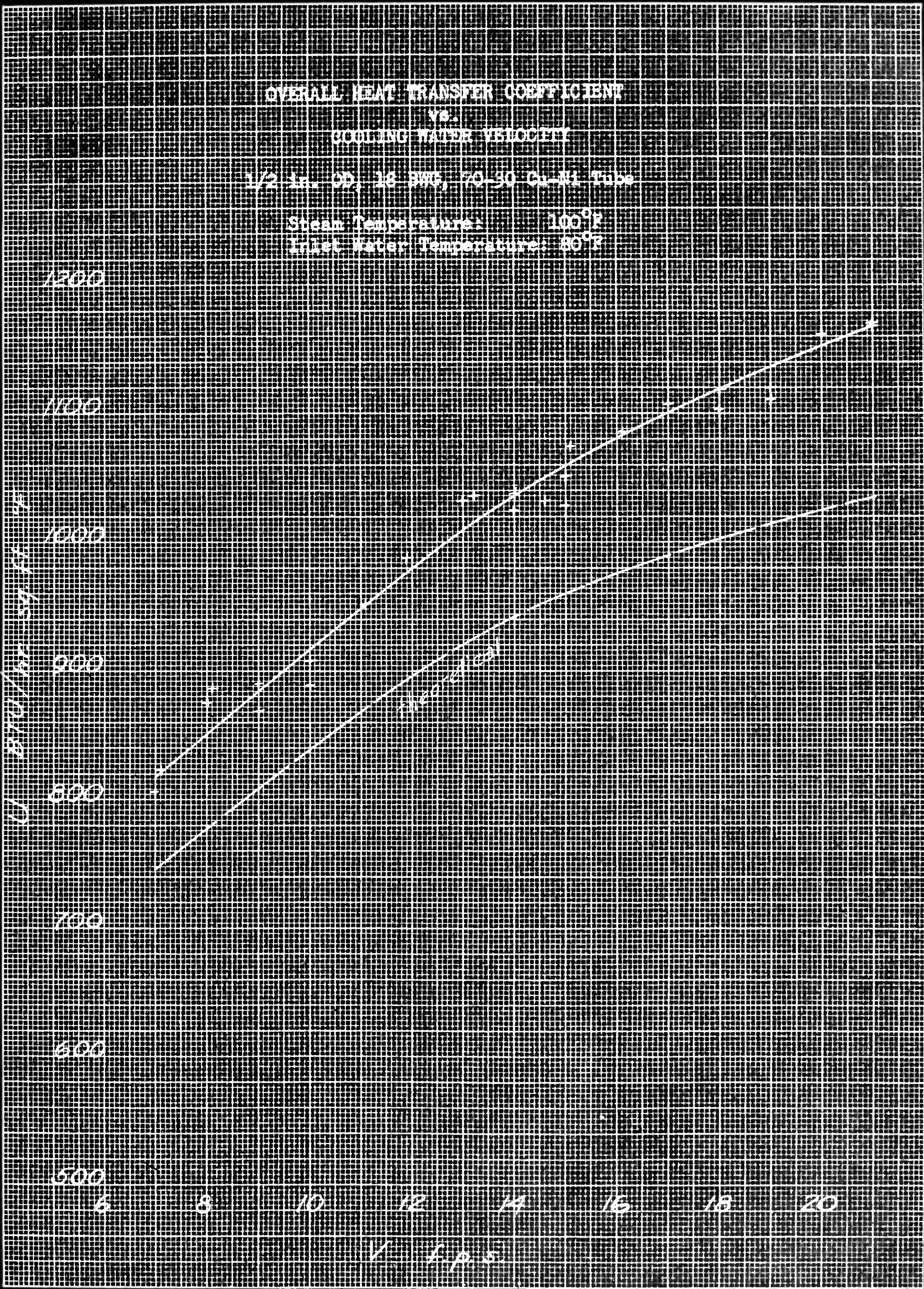

OVERALL HEAT TRANSFER COEFFICIENT
vs.
COOLING WATER VELOCITY
1/2 in. OD, 18 BWG, 70-30 Cu-Ni Tube
Steam Temperature: 100°F
Inlet Water Temperature: 80°F
1200
1100
1000
900
800
700
600
500
6
8
10
12
14
16
18
20
Theoretical
V f.p.s.

FIG. 8

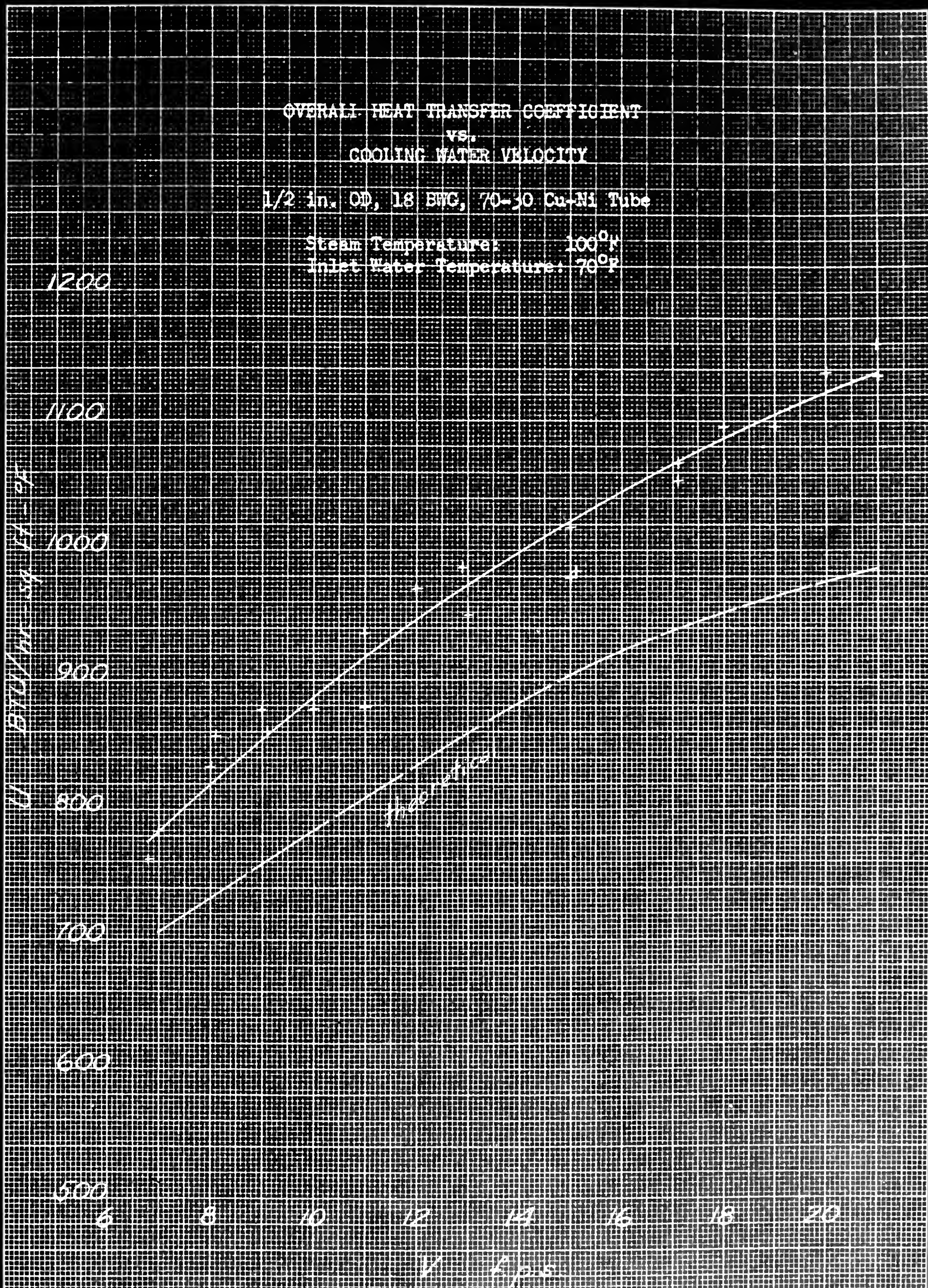

OVERALL HEAT TRANSFER COEFFICIENT
vs.
COOLING WATER VELOCITY
1/2 in. OD, 18 BWG, 70-30 Cu-Ni Tube
Steam Temperature: 100°F
Inlet Water Temperature: 70°F
1200
1100
1000
900
800
700
600
500
6
8
10
12
14
16
18
20
theoretical
V fps

FIG. 9

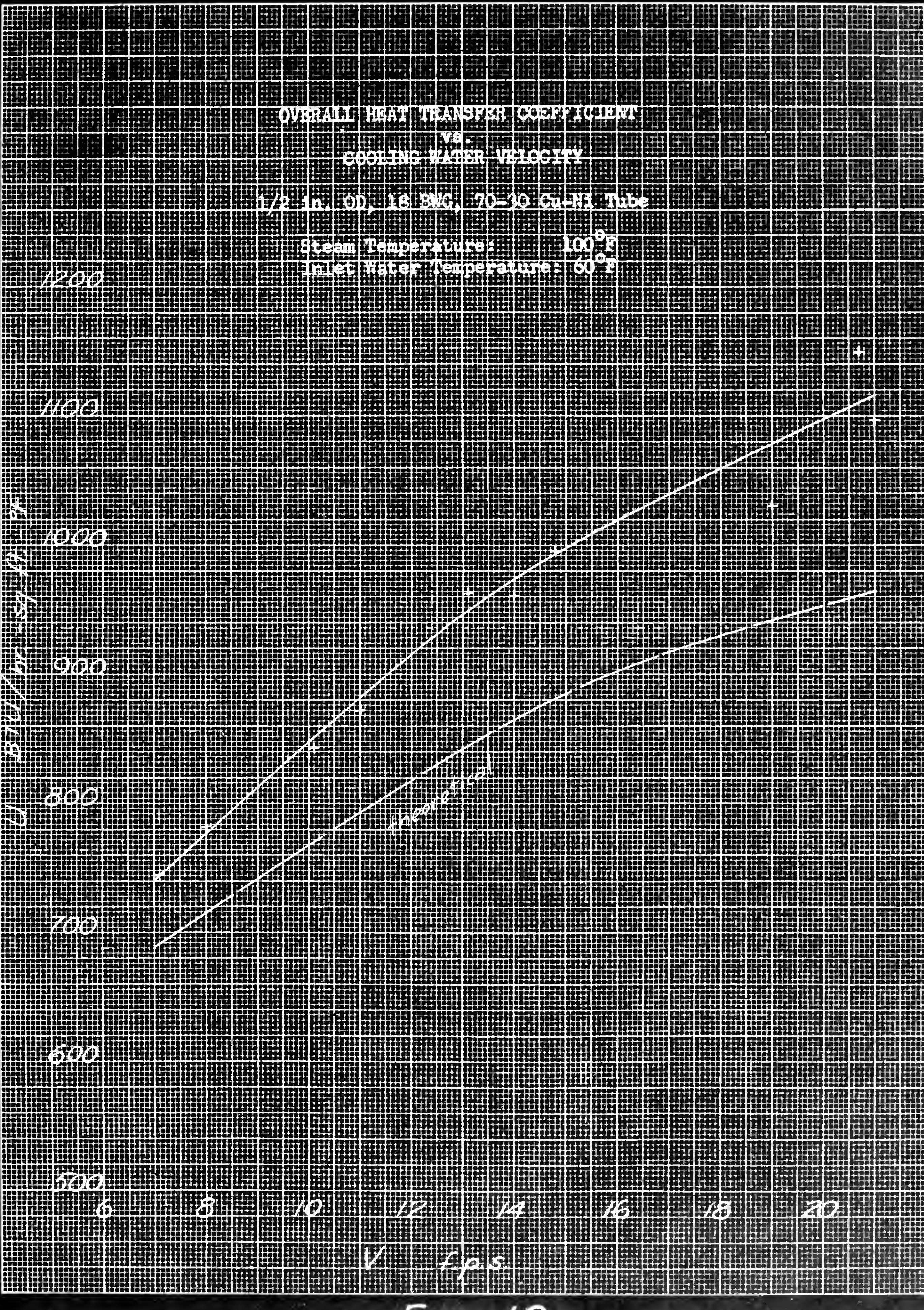
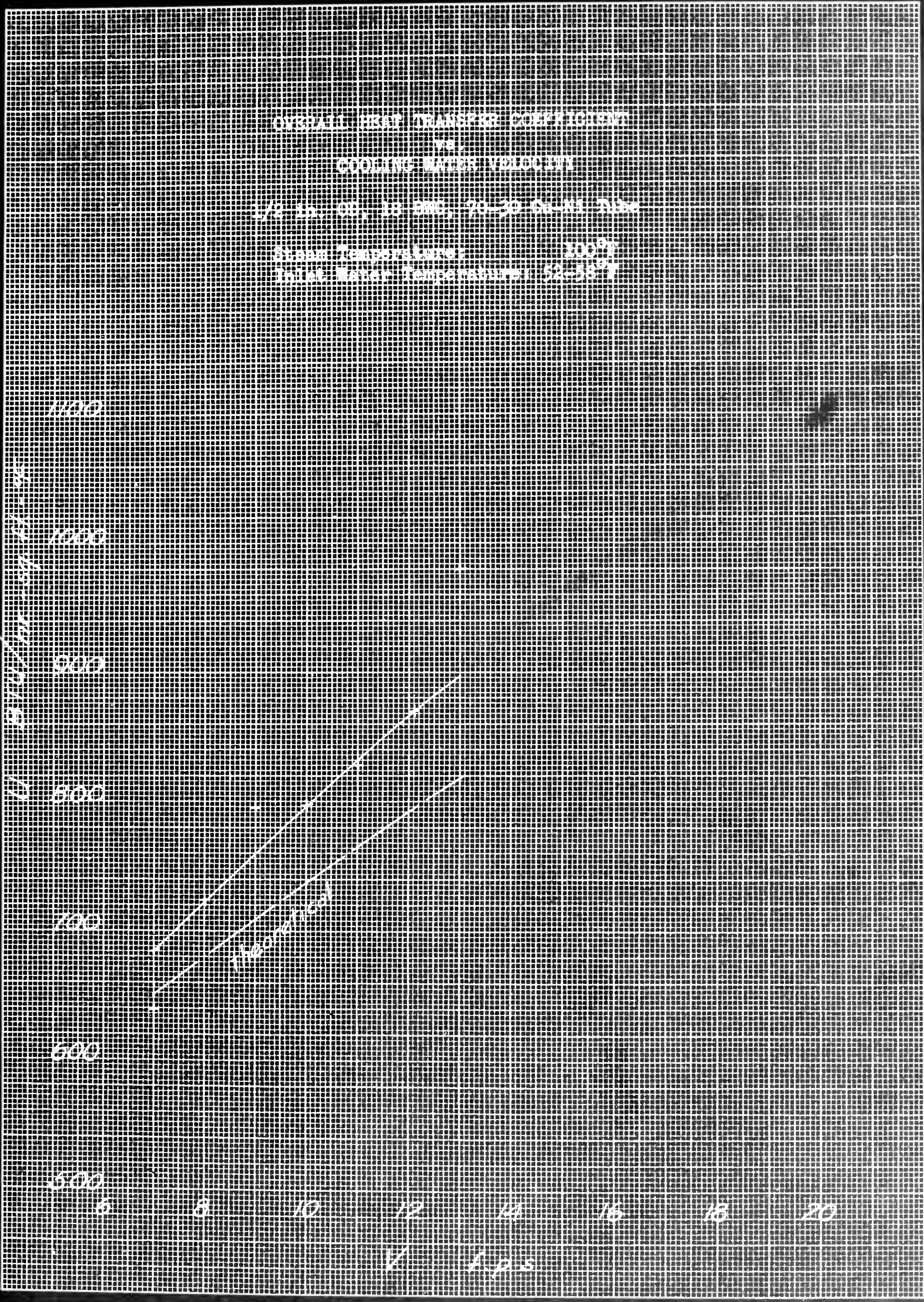

OVERALL HEAT TRANSFER COEFFICIENT
vs.
COOLING WATER VELOCITY
1/2 in. OD, 18 BWG, 70-30 Cu-Ni Tube
Steam Temperature: 100°F
Inlet Water Temperature: 60°F
1200
1100
1000
900
800
700
600
500
6
8
10
12
14
16
18
20
theoretical
V f.p.s.

FIG. 10



OVERALL HEAT TRANSFER COEFFICIENT
vs.
COOLING WATER VELOCITY
1/2 in. OD, 18 BWG, 70-30 Cu-Ni Tube
Steam Temperature: 100°F
Inlet Water Temperature: 52-58°F
1100
1000
900
800
700
600
500
U BTU/hr-sq ft-°F
6
8
10
12
14
16
18
20
V f.p.s
theoretical

FIG. 11

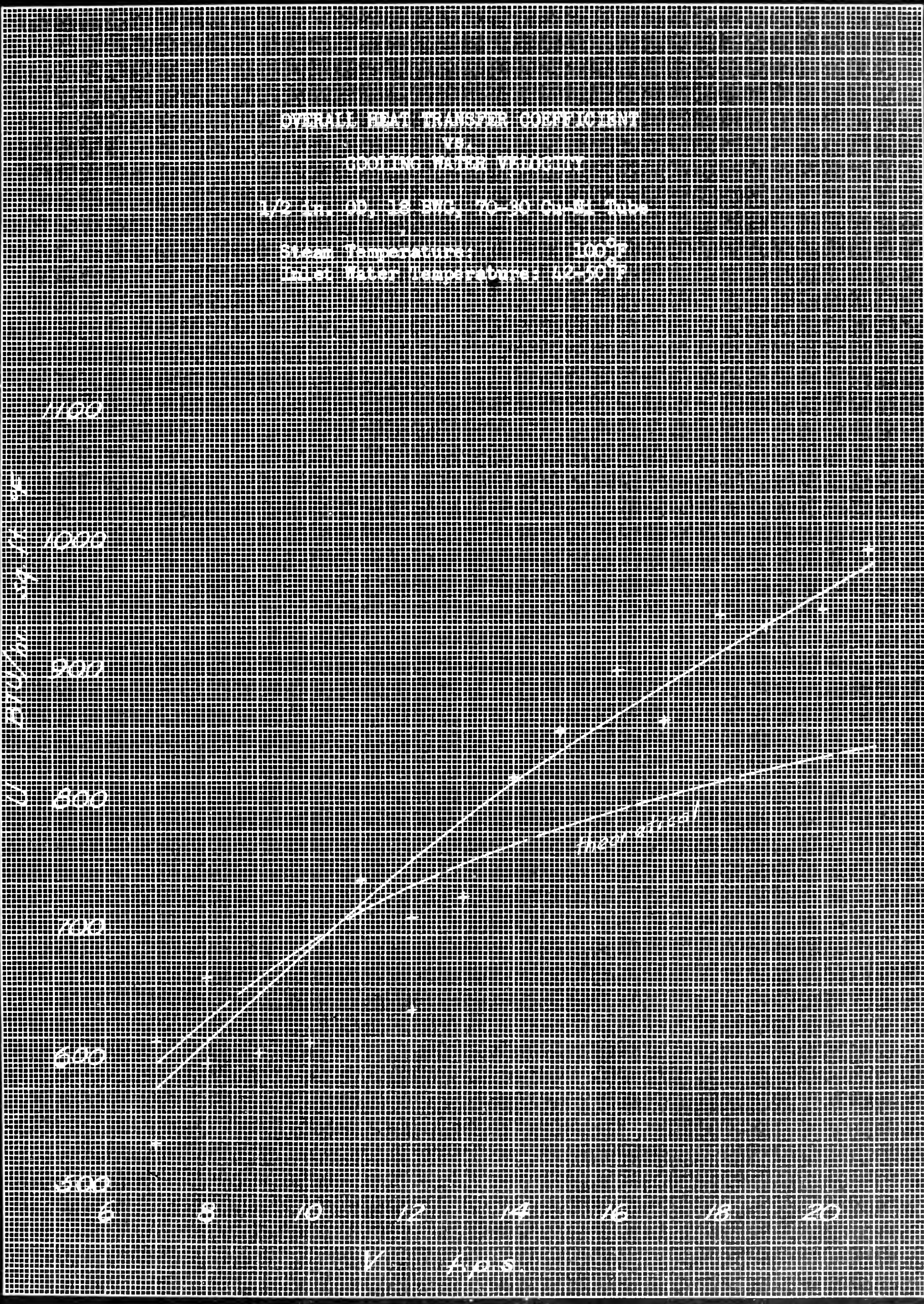

OVERALL HEAT TRANSFER COEFFICIENT
vs.
COOLING WATER VELOCITY
1/2 in. OD, 18 BWG, 70-30 Cu-Ni Tube
Steam Temperature: 100°F
Inlet Water Temperature: 42-50°F
1100
1000
900
800
700
600
500
6
8
10
12
14
16
18
20
theoretical
V ft.p.s.

FIG. 12

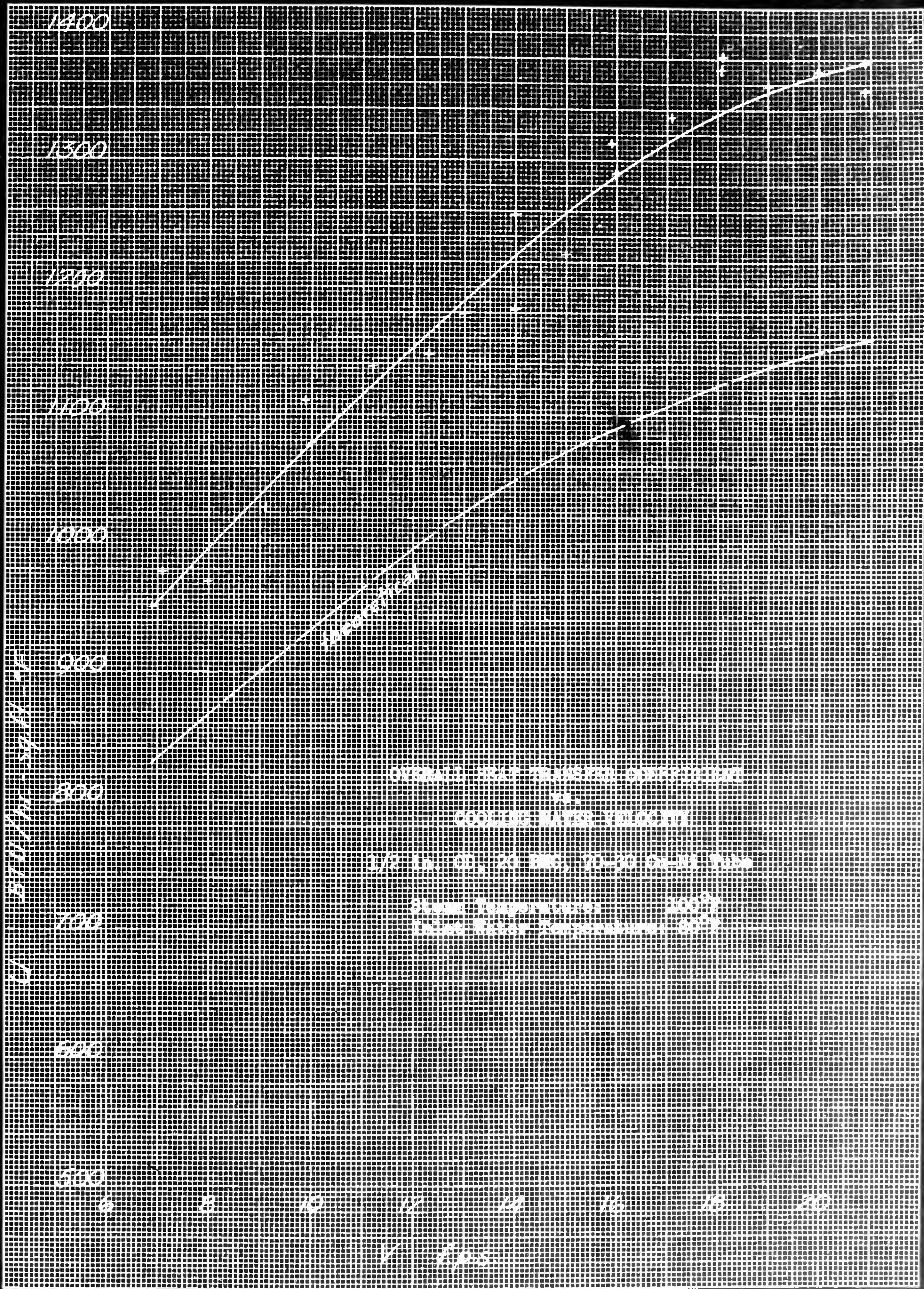

1400
1300
1200
1100
1000
900
800
700
600
500
U BTU/hr-sq ft-°F
6
8
10
12
14
16
18
20
V fps
Theoretical
OVERALL HEAT TRANSFER COEFFICIENT
vs.
COOLING WATER VELOCITY
1/2 in. OD, 20 BWG, 70-30 Cu-Ni Tube
Steam Temperature:
Inlet Water Temperature:

FIG. 13

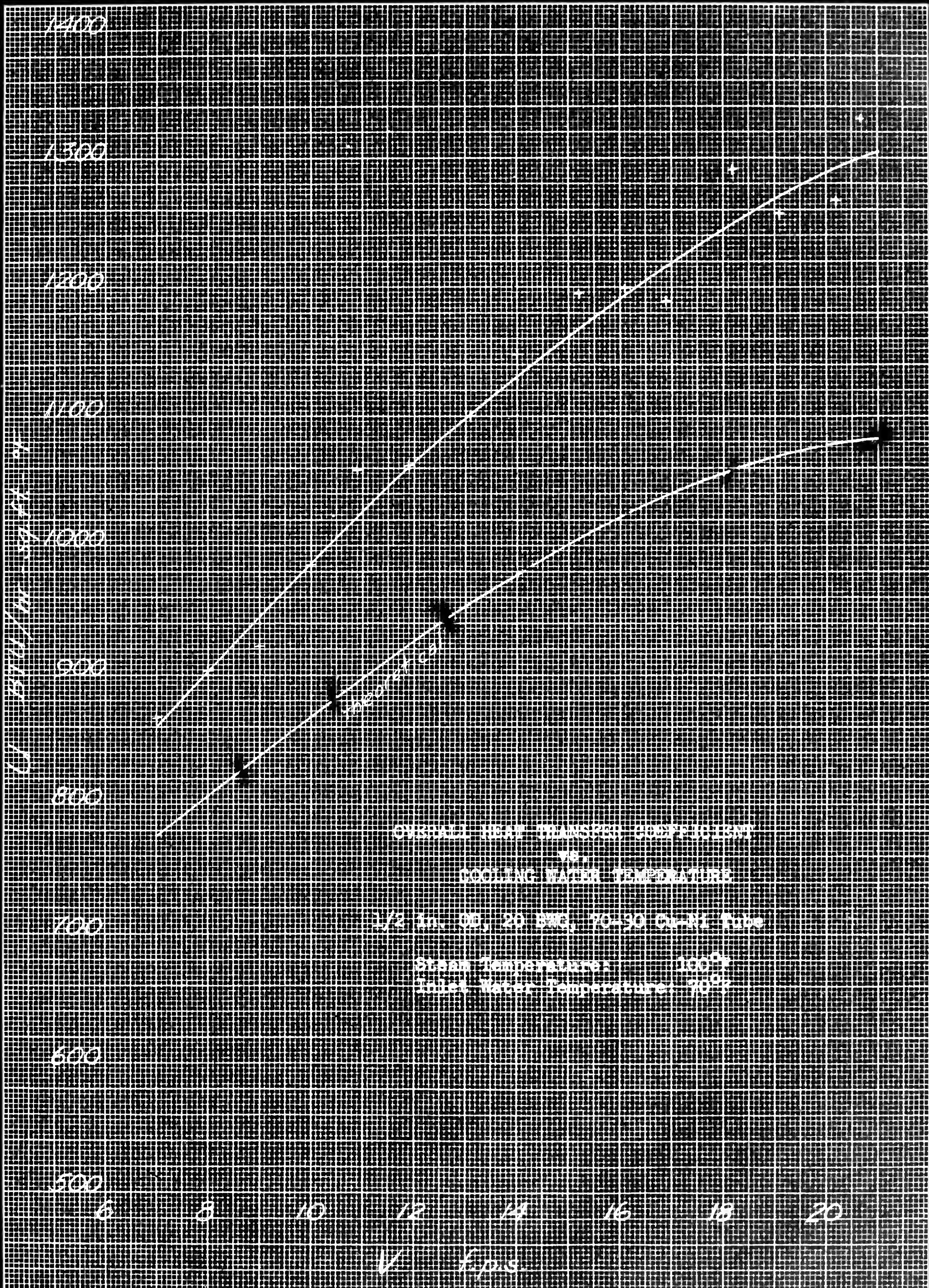

1400
1300
1200
1100
1000
900
800
700
600
500
6
8
10
12
14
16
18
20
V f.p.s.
theoretical
OVERALL HEAT TRANSFER COEFFICIENT
vs.
COOLING WATER TEMPERATURE
1/2 in. OD, 20 BWG, 70-30 Cu-Ni Tube
Steam Temperature: 100°F
Inlet Water Temperature: 70°F

FIG. 14

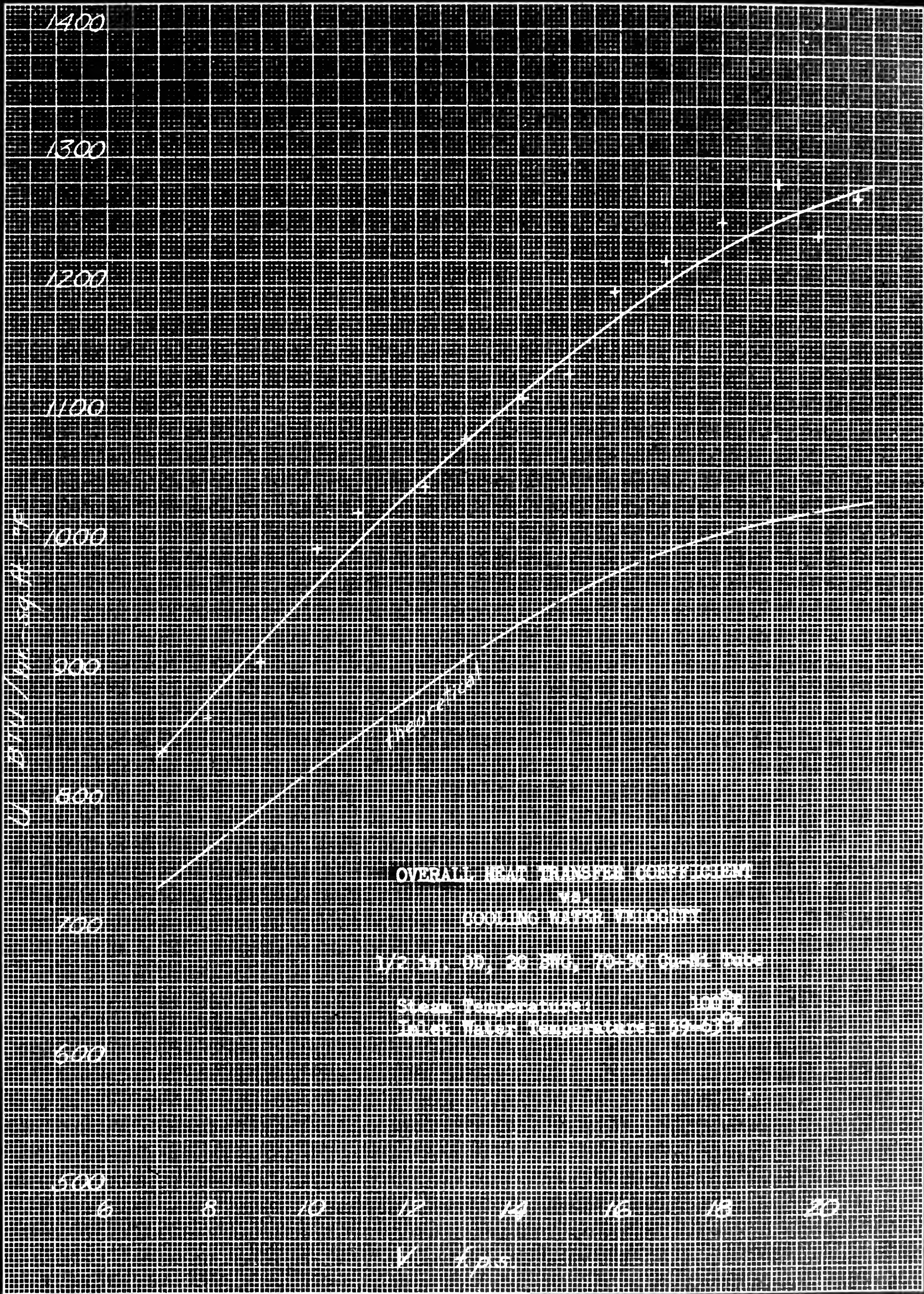

1400
1300
1200
1100
1000
900
800
700
600
500
6
8
10
12
14
16
18
20
V fps
theoretical
OVERALL HEAT TRANSFER COEFFICIENT
vs.
COOLING WATER VELOCITY
1/2 in. OD, 20 BWG, 70-30 Cu-Ni Tube
Steam Temperature: 100°F
Inlet Water Temperature: 59-63°F

FIG. 15

ANALYSIS OF RESULTS

The experimental values of overall heat transfer coefficient are plotted against cooling water velocity on the preceding pages and compared with the theoretical coefficients calculated in the following manner.

The overall heat transfer coefficient, U, in the general equation of heat transfer, $q = UA \Delta t_m$, may be separated into the steam condensate film coefficient, the tube wall resistance and the water film coefficient, by an expression for the sum of resistance:

$$\frac{1}{U} = \frac{1}{h_s} + \frac{LD_o}{kD_a} + \frac{D_o}{h_w D_i} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \quad (1)$$

The resistance of the tube wall, LD_o/kD_a, as defined by Fourier's Law and equation 1, is calculated from the wall thickness, average and outside diameters, and thermal conductivity of the tube.

The resistance of the water film, $D_o/h_w D_i$, is calculated from tube dimensions and the Dittus-Boelter equation:

$$h_w = 0.0225 \frac{k}{D_i} \left(\frac{D_i V \rho}{\mu} \right)^{0.8} \left(\frac{c \mu}{k} \right)^{0.4} \quad . \; . \; . \quad (2)$$

where the properties k, ρ, μ and c are evaluated at the mean of inlet and outlet water temperatures.

Combining the tube wall and water film resistances, and knowing the heat transfer rate and outside tube area from the experimental data, the temperature drop across the tube wall and waterfilm is computed. Subtracting this value from the experimental log mean temperature difference gives the temperature drop across the steam condensate film.

The steam condensate film coefficient is calculated by means of the Nusselt equation for condensing pure vapors on a single horizontal tube:

$$h_s = 0.725 \left(\frac{k^3 \rho^2 g \lambda}{D_o \mu \Delta t} \right)^{1/4} \quad \ldots\ldots (3)$$

in which the properties k, ρ, μ and λ are evaluated at the average temperature of the condensate film.

Several theoretical coefficients calculated in this manner from the experimental data (Table XIII) are employed to establish the curve of theoretical heat transfer coefficient vs. cooling water velocity shown on the graph for each experimental situation.

It is to be noted that the data for 1/2 in. O. D., 18 BWG tube at inlet water temperature range 42-50°F (Table IX, Fig. 12) differs markedly from the trend of the other data. The scattering of points indicates some doubt as to the reliability of this particularly set of data, and certainly demonstrates poor reproducibility. In this series of runs considerable experimental difficulty was encountered in maintaining the low inlet water temperature desired. Circulating water was taken direct from the underground city mains during the coldest period of the winter months, and was not recirculated. This procedure led to greater water temperature variation during a run than when the coolers could be used.

Perusal of the plotted curves shows the experimental values of U to follow in form the theoretical values, but to exceed the later by deviations varying from 5 to 23 percent.

The percent deviations of U experimental above U theoretical (Table XIV) are plotted in Fig. 16, and a curve is drawn showing the mean deviation as a function of circulating water velocity. Using this as a correction curve for the values of U theoretical in Table XIV, and comparing the values of U experimental with corrected U theoretical gives the results shown. The maximum deviation is 6.0 percent; the average deviation is 2.5 percent; the probable deviation is 1.95 percent.

Table XIII. Calculated Theoretical Overall Heat Transfer Coefficients.

Tube Size: 5/8 in. O. D., 18 BWG

Run	t_s	t_1	t_2	V	h_w	h_s	U
1	99.30°F	80.18°F	85.01°F	7.0 fps	1535	2920	726
4	100.28	80.64	84.79	10.1	2010	2850	836
9	99.91	80.25	83.39	15.0	2835	2610	940
24	100.19	79.92	82.51	19.9	3330	2520	985
106	99.1	69.16	76.26	7.1	1460	2740	696
84	99.4	70.18	75.30	13.0	2320	2550	859
109	99.8	69.03	73.06	19.0	3140	2270	927
206	99.7	59.84	68.57	8.0	1495	2565	692
204	100.0	61.34	68.44	11.0	1985	2360	780
203	100.3	60.48	66.80	14.0	2360	2260	829
91	100.0	57.22	66.92	7.0	1345	2500	648
93	99.9	55.09	63.21	11.0	1895	2300	756
105	100.2	53.60	59.25	19.8	2950	2035	865
Tube Size: 1/2 in. O. D., 18 BWG.							
28	99.57	80.02	86.38	7.0	1620	3270	746
51	99.55	79.96	84.33	14.0	2780	2880	942
54	100.16	79.80	83.33	21.0	3850	2710	1035
125	100.9	69.67	79.58	7.0	1538	2950	706
129	100.8	70.17	76.46	15.0	2800	2520	904
132	100.8	70.24	75.63	20.0	3520	2460	976
194	99.8	60.51	71.62	8.0	1680	2565	716
196	99.5	60.57	68.68	14.0	2620	2400	865
142	100.0	59.15	66.08	20.0	3310	2530	964
140	100.2	56.93	69.16	7.0	1428	2540	651
136	100.4	56.56	66.97	10.0	1880	2330	737
141	100.2	57.35	67.04	11.0	2035	2320	765
151	100.8	50.03	61.73	7.0	1360	2050	600
160	100.4	49.26	60.83	8.0	1502	2080	634
148	99.7	46.46	56.11	14.0	2270	2055	770
154	99.9	43.18	51.98	18.9	2780	2020	828
Tube Size: 1/2 in. O. D., 20 BWG.							
55	99.53	79.77	86.37	6.9	1580	3525	829
72	99.8	80.03	84.34	16.0	3065	2820	1089
74	99.9	80.15	83.68	20.9	3805	2690	1159
164	99.5	70.11	78.49	8.0	1687	2750	807
166	99.7	69.84	76.29	14.0	2635	2530	978
168	100.2	69.72	75.00	20.7	3580	2415	1082
179	101.0	59.94	71.15	8.0	1597	2540	765
178	100.1	60.56	69.22	13.0	2345	2390	910
183	100.1	62.13	68.96	19.1	3175	2330	1020

Table XIV. Comparison of Experimental and Theoretical Values of U.

Tube Size	t_1		V 7	11	15	20
5/8 in., 18	80°F	Uexp	827	980	1050	1099
		Uth.	726	865	940	985
		%Dev.	13.9	13.3	11.7	11.5
	corr.	Uth.	812	985	1087	1152
		%Dev.	+1.8	-0.5	-3.4	-4.6
5/8 in., 18	70°F	Uexp.	790	945	1035	1089
		Uth.	692	816	888	934
		%Dev.	14.1	15.8	16.6	16.6
	corr.	Uth.	774	930	1027	1093
		%Dev.	+2.1	+1.6	+0.7	-0.4
5/8 in., 18	60°F	Uexp.	760	908	1004	
		Uth.	654	780	840	
		%Dev.	16.2	16.4	19.6	
	corr.	Uth.	731	888	971	
		%Dev.	+4.0	+2.3	+3.4	
5/8 in., 18	53-58°F	Uexp.	737	890	985	1043
		Uth.	648	756	825	866
		%Dev.	13.8	17.8	19.3	20.4
	corr.	Uth.	725	861	953	1013
		%Dev.	+1.7	+3.4	+3.4	+3.0
1/2 in., 18	80°F	Uexp.	818	950	1060	1153
		Uth.	746	869	960	1025
		%Dev.	9.2	9.2	10.4	12.5
	corr.	Uth.	845	990	1110	1200
		%Dev.	-3.2	-4.0	-4.5	-3.9
1/2 in., 18	70°F	Uexp.	784	917	1023	1123
		Uth.	706	810	904	976
		%Dev.	11.0	13.1	13.2	15.1
	corr.	Uth.	790	923	1044	1142
		%Dev.	-0.8	-0.7	-1.9	-1.7
1/2 in., 18	60°F	Uexp.	740	882	999	1098
		Uth.	688	793	885	953
		%Dev.	7.6	11.2	12.8	15.2
	corr.	Uth.	770	903	1023	1115
		%Dev.	-3.9	-2.3	-2.3	-0.2

Tube Size	t_1		V			
			7	11	15	20
1/2 in., 18	52°-58°F	Uexp.	684	832		
		Uth.	651	765		
		%Dev.	5.1	8.8		
	corr.	Uth.	728	871		
		%Dev.	-6.0	-4.5		
1/2 in., 20	80°F	Uexp.	955	1116	1259	1369
		Uth.	833	964	1071	1149
		%Dev.	14.6	15.7	17.5	19.1
	corr.	Uth.	931	1098	1239	1344
		%Dev.	+2.5	+1.6	+1.6	+1.9
1/2 in., 20	70°F	Uexp.	860	1027	1162	1289
		Uth.	776	898	1002	1078
		%Dev.	10.8	14.3	16.0	19.7
	corr.	Uth.	868	1023	1159	1261
		%Dev.	-0.9	+0.4	+0.3	+2.2
1/2 in., 20	59°-63°F	Uexp.	837	1007	1146	1266
		Uth.	734	855	961	1027
		%Dev.	14.0	17.7	19.2	23.2
	corr.	Uth.	820	974	1111	1202
		%Dev.	+2.1	+3.4	+3.2	+5.3

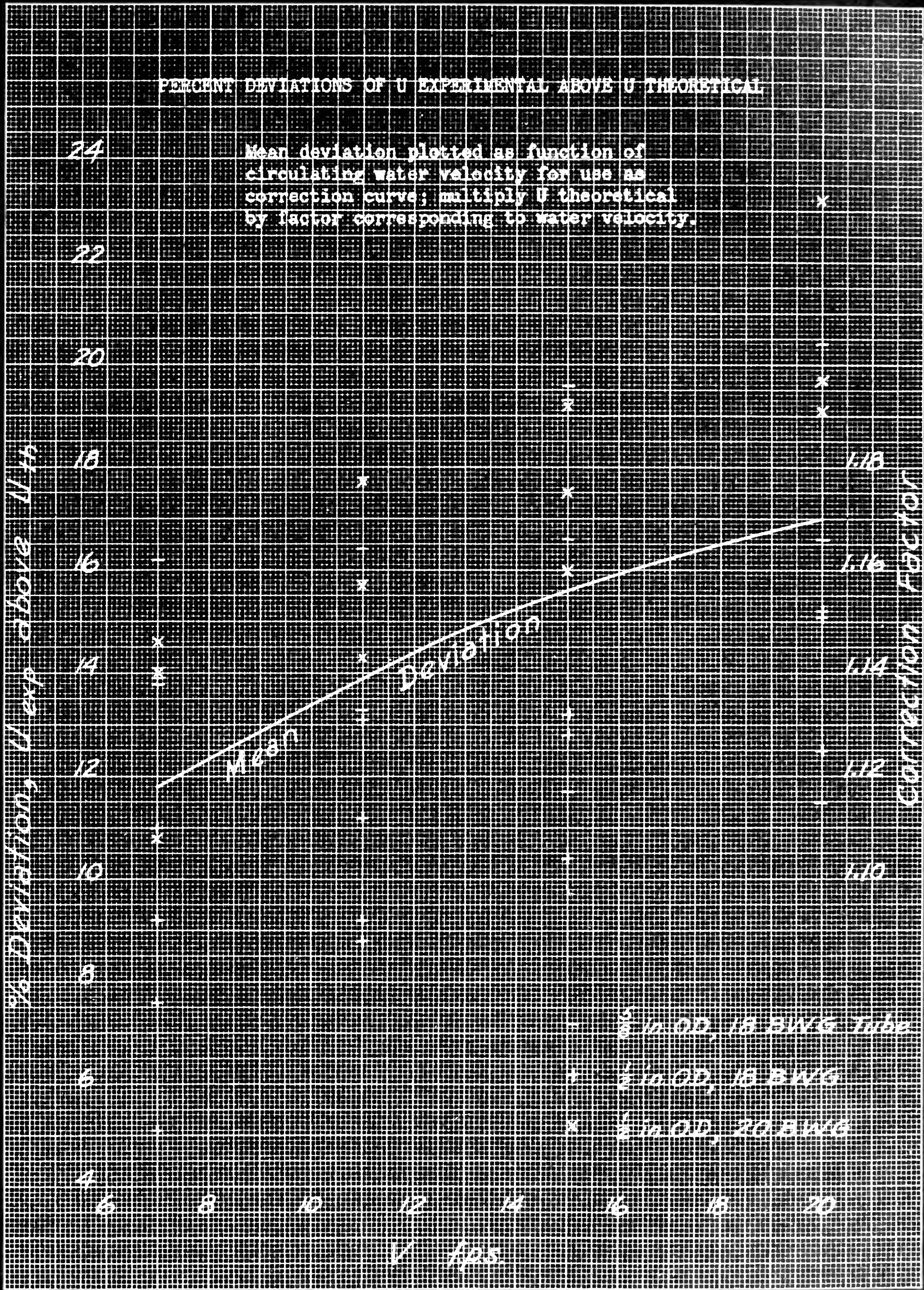

PERCENT DEVIATIONS OF U EXPERIMENTAL ABOVE U THEORETICAL
Mean deviation plotted as function of circulating water velocity for use as correction curve; multiply U theoretical by factor corresponding to water velocity.
% Deviation, U exp above U th
Correction Factor
Mean Deviation
5/8 in OD, 18 BWG Tube
1/2 in OD, 18 BWG
1/2 in OD, 20 BWG
V fps
4
6
8
10
12
14
16
18
20
22
24
1.10
1.12
1.14
1.16
1.18

FIG. 16

CONCLUSIONS

In such a study as this wherein investigation of heat transfer characteristics is limited to a few smaller sizes of condenser tubes of a particular metal and using only steam and water as the fluid media, it would be unwise to propose a new, empirical equation applicable only to this specific situation. Also since the Nusselt and Dittus-Boelter equations are well known and established in the literature for general use, it would be equally pointless to suggest a new set of coefficients to bring the results of those equations into closer agreement with this set of experimental data.

Instead it is thought preferable to use the accepted general equations and then multiply by a correction factor corresponding to the circulating water velocity to determine an overall heat transfer coefficient for practical design problems. Within the range of this investigation correction factors as determined from Figure 16 may be used to predict the overall heat transfer coefficient for a single, clean, horizontal tube, with a probable deviation of only two percent.

NOMENCLATURE

A	Outside tube area, sq. ft.
c	Specific heat, BTU/lb.-°F.
D	Diameter, ft.
g	Acceleration of gravity, 4.18 x 10^8 ft./hr.^{2}
h	Film coefficient, BTU/hr.-sq. ft.-°F.
H	Flowmeter gauge reading, cm.
k	Thermal conductivity, BTU-ft./hr.-sq. ft.-°F.
L	Length, ft.
q	Heat transfer rate, BTU/hr.
t	Temperature, °F.
U	Overall heat transfer coefficient, BTU/hr.-sq.ft.-°F.
V	Circulating water velocity, ft./sec.
w	Circulating water flow rate, lb./hr.
Δt_m	Log mean temperature difference, °F.
λ	Latent heat of evaporation, BTU/lb.
μ	Absolute viscosity, lb./ft.-sec. or lb./ft.-hr.
ρ	Density, lb./cu. ft.

Subscripts

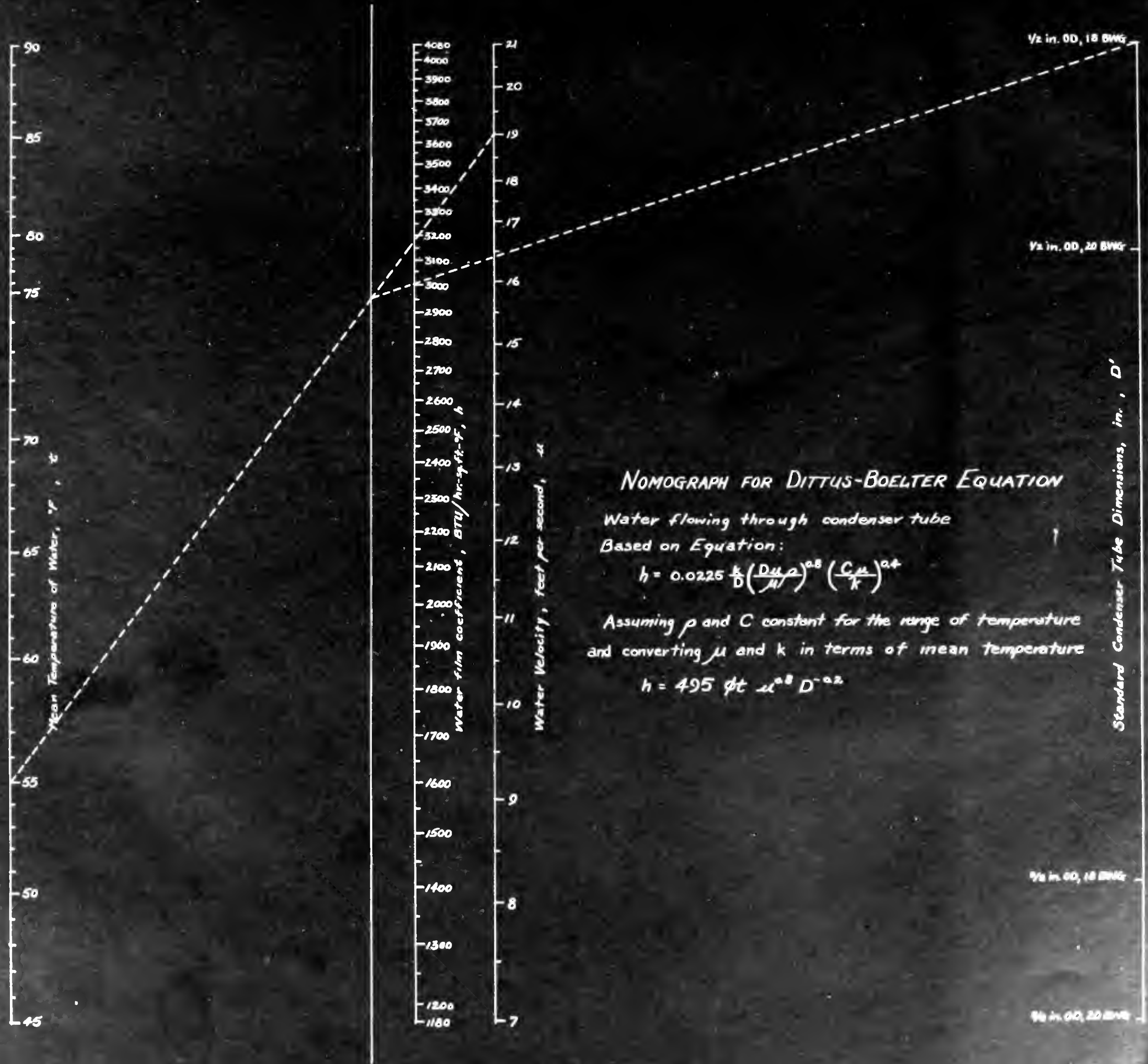
a	Average.
i	Inside.
o	Outside.
s	Steam, or condensate film.
w	Water film.
1	Inlet.
2	Outlet.

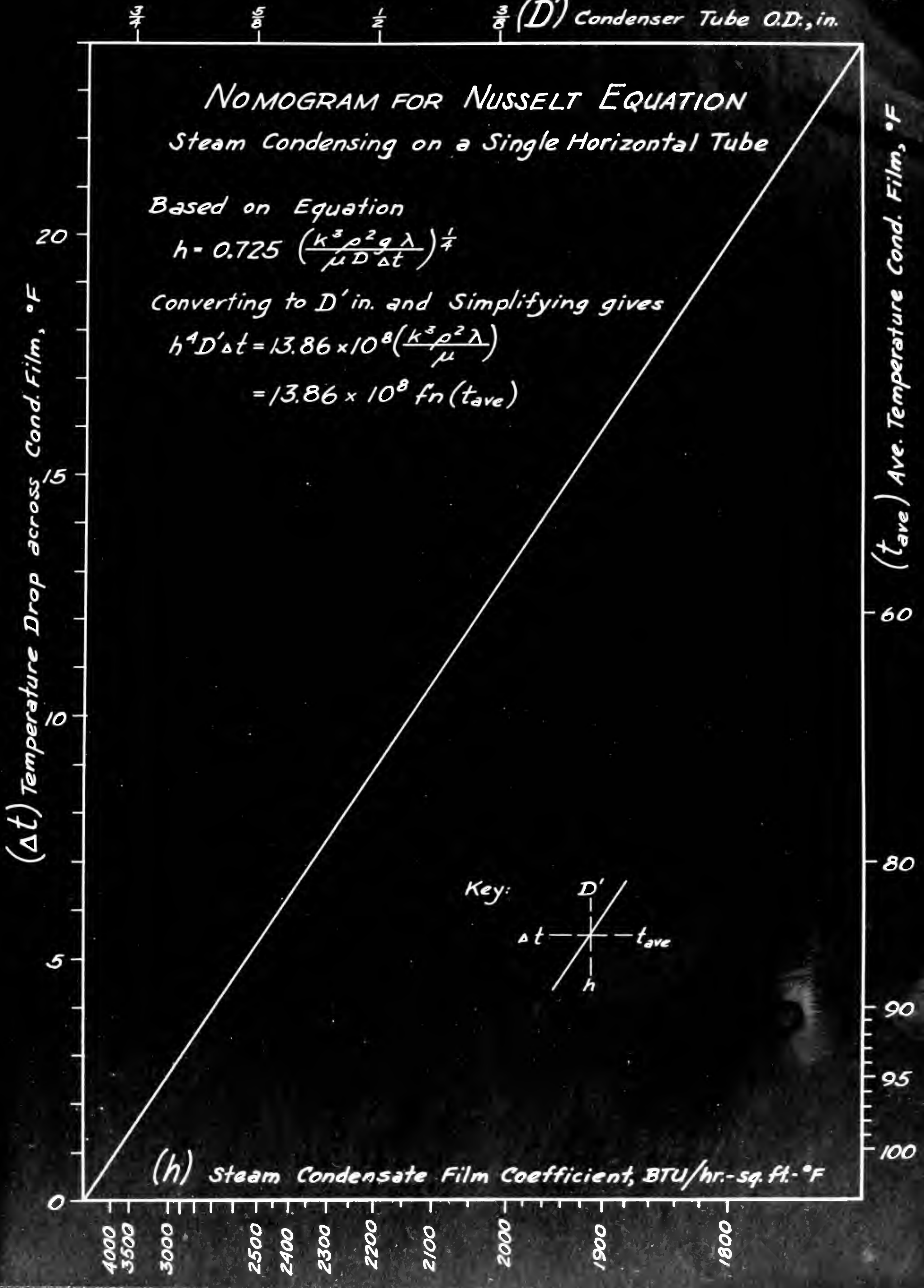
APPENDIX

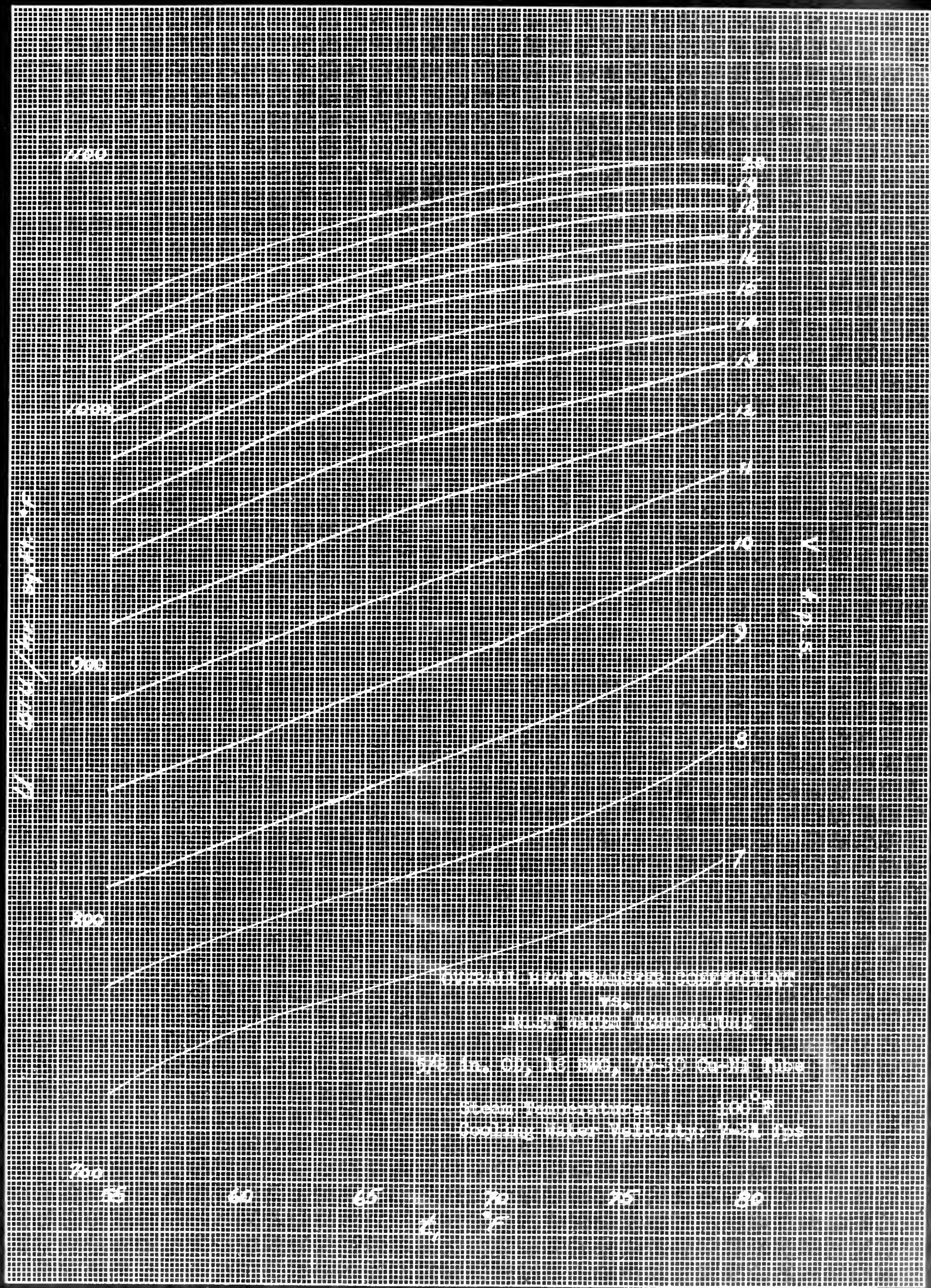
In a previous investigation using this same calorimeter and evaporator (H. J. McGregor, Lehigh U. Inst. of Research; unpublished report and data for The Heat Exchange Institute, 6 May 1946) it was shown that at the low velocities involved, variations in the steam velocity have a negligible effect on the overall heat transfer coefficient. That is to say, the condensate film coefficient does not vary with steam velocity.

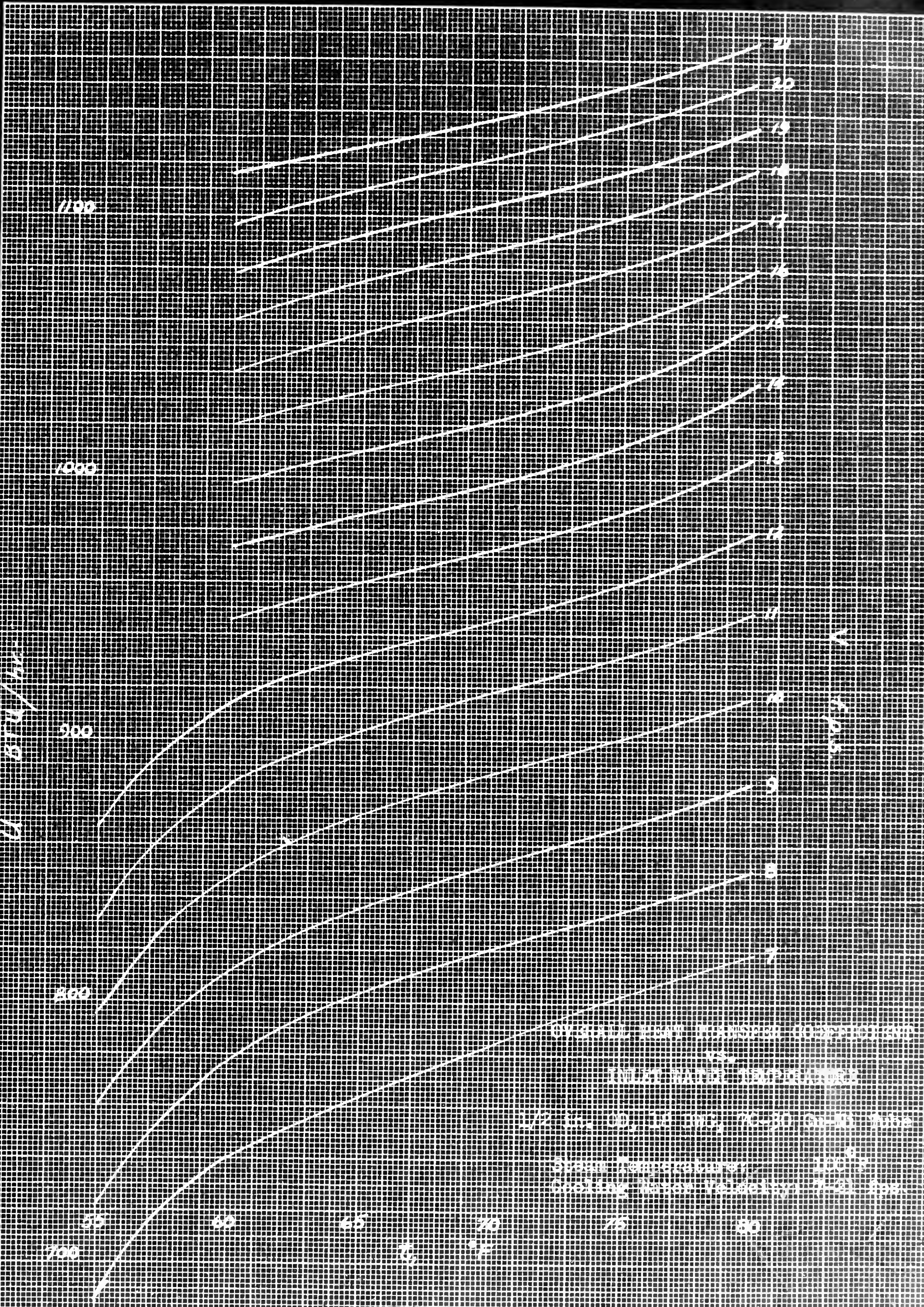
Steam velocity was varied by changing coil steam pressure in the evaporator from two to twelve pounds per square inch in a series of runs while holding all other variables constant. A brief summary of the data is given below:

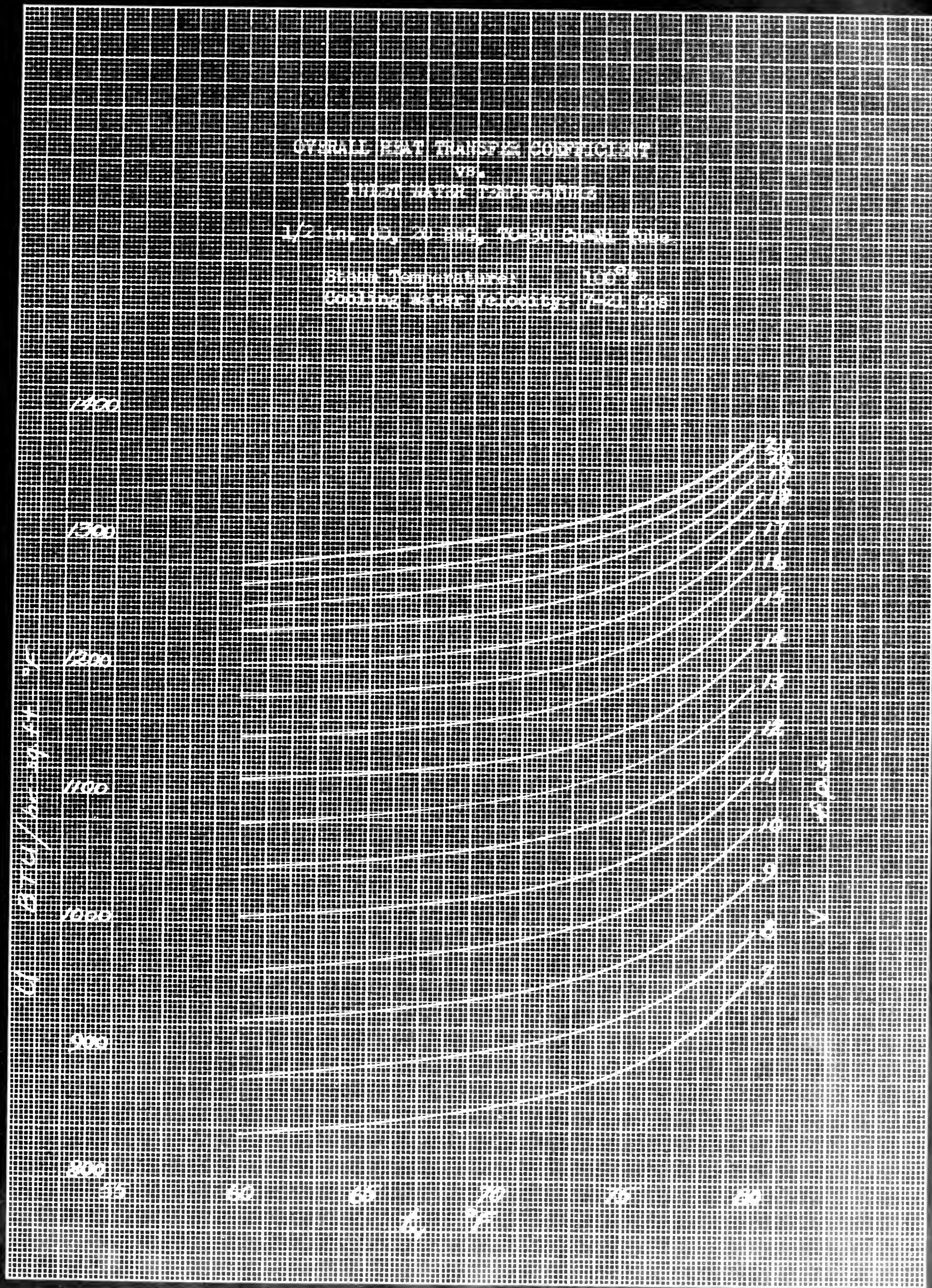
Coil Steam Pressure	t_s	t_1	V	U
12 psi	135.7°F	68.8°F	2.6 fps	501 BTU/hr.-sq.ft.-°F
5	135.7	68.7	2.6	526
2	133.7	69.0	2.7	527
3	136.9	70.5	2.6	524
4	134.9	70.3	2.6	513
5	139.7	70.3	2.6	524
9	137.2	69.3	2.6	524
5	137.2	70.0	2.6	527


NOMOGRAPH FOR DITTUS-BOELTER EQUATION
Water flowing through condenser tube
Based on Equation:
$h = 0.0225 \frac{k}{D}\left(\frac{Du\rho}{\mu}\right)^{0.8}\left(\frac{C\mu}{k}\right)^{0.4}$
Assuming ρ and C constant for the range of temperature
and converting μ and k in terms of mean temperature
$h = 495\ \phi t\ u^{0.8}\ D^{-0.2}$
Mean Temperature of Water, °F, t
90
85
80
75
70
65
60
55
50
45
Water film coefficient, BTU/hr-sq.ft.-°F, h
4080
4000
3900
3800
3700
3600
3500
3400
3300
3200
3100
3000
2900
2800
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1180
Water Velocity, feet per second, u
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
Standard Condenser Tube Dimensions, in., D'
1/2 in. OD, 18 BWG
1/2 in. OD, 20 BWG


NOMOGRAM FOR NUSSELT EQUATION
Steam Condensing on a Single Horizontal Tube
Based on Equation
$h = 0.725 \left(\frac{k^3 \rho^2 g \lambda}{\mu D \Delta t}\right)^{\frac{1}{4}}$
Converting to D' in. and Simplifying gives
$h^4 D' \Delta t = 13.86 \times 10^8 \left(\frac{k^3 \rho^2 \lambda}{\mu}\right)$
$= 13.86 \times 10^8 \, fn(t_{ave})$
(D') Condenser Tube O.D., in.
$\frac{3}{4}$
$\frac{5}{8}$
$\frac{1}{2}$
$\frac{3}{8}$
(Δt) Temperature Drop across Cond. Film, °F
0
5
10
15
20
(t_{ave}) Ave. Temperature Cond. Film, °F
60
80
90
95
100
(h) Steam Condensate Film Coefficient, BTU/hr.-sq.ft.-°F
4000
3500
3000
2500
2400
2300
2200
2100
2000
1900
1800
Key:
D'
Δt
t_{ave}
h


OVERALL HEAT TRANSFER COEFFICIENT
vs.
INLET WATER TEMPERATURE
5/8 in. OD, 18 BWG, 70-30 Cu-Ni Tube
Steam Temperature: 100 °F
Cooling Water Velocity: 7-20 fps
U BTU/hr sq ft °F
1100
1000
900
800
700
55
60
65
70
75
80
t, °F
V fps
20
19
18
17
16
15
14
13
12
11
10
9
8
7


21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
1100
1000
900
800
700
U BTU/hr
V fps
55
60
65
70
75
80
t_1 °F
OVERALL HEAT TRANSFER COEFFICIENT
vs.
INLET WATER TEMPERATURE
1/2 in. OD, 18 BWG, 70-30 Cu-Ni Tube
Steam Temperature: 100 °F
Cooling Water Velocity: 7-21 fps


OVERALL HEAT TRANSFER COEFFICIENT
VS.
INLET WATER TEMPERATURE
1/2 in. OD, 20 BWG, 70-30 Cu-Ni Tube
Steam Temperature: 100°F
Cooling Water Velocity: 7-21 fps
1400
1300
1200
1100
1000
900
800
55
60
65
70
75
80
°F
fps
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7